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PHILOSOPHY OF HEALTH.

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THE

PHILOSOPHY OF HEALTH;

OR,

AN EXPOSITION

OF THE

PHYSIOLOGICAL AND SANITARY CONDITIONS

CONDUCIVE TO

HUMAN LONGEVITY AND HAPPINESS.

BY

SOUTHWOOD SMITH, M.D.

ELEVENTH EDITION, REVISED AND ENLARGED.

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PREFACE TO THE ELEVENTH EDITION.

In presenting to the public, under somewhat peculiar circumstances, the present edition of a work which had already established itself many years ago, some slight explanation may be necessary.

The "Philosophy of Health" was one of the first efforts to render the main truths of physiology familiar to unprofessional persons; and the importance in the Author's eyes of such familiarity he explains in his first chapter. The work was so successful that, by the year 1854, no fewer than ten reprints of it had been made in this country and in America. The reprints were unrevised; for during many years another object entirely absorbed the Author's time and energies. In the course of his practice as a physician, he saw so much disease and misery arising from the neglected state of those districts where the masses of the people are congregated, that he could no longer rest in the vain effort to stem the tide of the evil by medicine; he turned rather to the work of prevention, by purifying the fountain-heads of corruption and infection, and thus became a leader in the small band of pioneers who first roused the country and the Legislature to the necessity of Sanitary Reform.

The work of spreading sanitary principles, and, subsequently, the duties of the position he occupied in the Public Departments which were charged with carrying those principles into practical effect, engrossed his whole time. But when the sanitary cause was

In that name may I thank all those, whether known to me or not, who, whilst he who bore it was still amongst us, gave him their valuable assistance in his labours, especially that old and trusted friend with whom he read over much of the book whilst still in manuscript, whose ready sympathy gave him so much pleasure, and whose time and energy so much important assistance. I mean R. D. Grainger, Esq., F.R.S., F.R.C.S., for a long period Lecturer on Physiology at St. Thomas's Hospital.

I also take this opportunity of thanking those friends who, since the work has been in my hands, have shared my desire that it should be brought out in an adequate manner, and who have in various ways furthered the accomplishment of this object. My obligations in this respect are very great towards Thomas Baker, Esq., of the Inner Temple, Barrister-at-Law.

The plates in the present edition are principally new, many of those which originally belonged to the work having been found unsuitable, in consequence of the new light which has been thrown on physiology, and the fresh matter requiring entirely new illustration.

Let me say, in conclusion, that I have felt deeply the responsibility that has rested upon me while endeavouring to make this edition all that its author would have wished. I, who was with him always, know how great his own interest in it was, and I would hope that the solemn charge intrusted to me has not been, to any great extent, neglected. My grandfather had but one object in life: all he did tended towards it. May this, his early and his last work, forward that object—the diffusion of such knowledge of the laws of health as shall lead to an increase of the mental and moral power of his fellow-creatures.

G. H.

HAMPSTEAD, *December*, 1864.

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PHILOSOPHY OF HEALTH.

CHAPTER I.

Characters by which living beings are distinguished from inorganic bodies—Characters by which animals are distinguished from plants—Actions common to plants and animals—Actions peculiar to animals—Reasons why the structure of an animal is more complex than that of a plant.

EVERY one can distinguish between a plant and a stone, and between an animal and a plant, but the real differences between them are not known to every one, and are not obvious without reflection.

In a plant and animal certain movements take place, as the motion of the sap in a plant, and of the blood in an animal, which do not exist in a stone. These movements are produced by a definite mechanism; that is, by certain structures adapted and designed to accomplish a given result, as in the case just referred to, the circulation of the sap and of the blood. The apparatus or instrument is termed an organ, and the action of an organ is termed its function. Organisation is the building up of organs. A body furnished with organs is organised. When in the exercise of its organs it is alive. The action of its organs is its life.

Living beings are organisms. Nothing enters into their composition which does not perform or minister to the performance of a function. The roots, leaves, and flowers of a plant; the heart, brain, and stomach of an animal, are so many organs, to each of which a definite office is assigned. These, taken together, constitute the being, and their action comprises its life. Hence the possession of organs is one character by which an organised being is distinguished from an inorganic body.

The organs of which a living being is composed consist of a union of fluid and solid parts. An inorganic body may be entirely gaseous, liquid, or solid; but in every organised being there is an intermixture of solids and fluids; and so intimate is their union that there is no organic fluid which does not hold solid matter in solution, and no solid that does not contain fluid; while each readily passes from one into the other.

In passing from a liquid to a solid state, few organic fluids assume a crystalline structure. Inorganic compounds in becoming solid commonly take a crystalline form; but in organised beings this is extremely rare; and there are special provisions for preventing it. Extensive crystallization would be incompatible with the processes of life.

Nor is there any living being whose form is geometrically regular, like a crystal. There is no known living form whose faces are plane faces. They are all more or less curved and irregular.

Living beings increase in bulk by a peculiar process, termed growth; in which extraneous matter is taken into the body, and converted into the true and proper substance of the creature that absorbs it. In a growing body all its parts enlarge proportionally and relatively. The root, stem, and branch; the bone, muscle, and nerve, all acquire additional size in fixed and appropriate relation to each other, and to the whole. And the process stops at a definite point. After a certain size is attained no further enlargement of the body takes place—all which circumstances present a marked contrast to the mode in which inorganic substances increase in bulk; which is simply by the apposition of particle to particle, to the extent of which there is commonly no definite limit.

Organised beings are in a state of perpetual motion and mutation: inorganic bodies, some great geographical phenomena excepted, are in a state of rest. When once the elements composing a crystal are combined, they remain, often for ages, in a state of perfect quiescence. Disturbance of that state of rest, new motions set up among its component particles, involves its destruction. On the contrary, the constituent particles of organised beings are always in motion, always undergoing decomposition and re-combination, and when these transformations stop, life is at an end. Life and change are one.

The peculiar mode in which these incessant motions are excited and maintained in a living creature is equally distinctive of it. Air, water, heat, light, electricity, food, excite and maintain definite actions.

The exciting bodies are called stimulants, and the actions they produce, since they take place only in organised and living structures, are called vital. Without the structure, without the stimulus, there is no action: both must combine and co-operate. Life consists of vital actions, sustained in organised structures by the excitement of stimulants.

Lastly, the existence of organised beings is cyclical. They derive their origin from a parent. They grow from an atom derived from a parent into an independent organism; on reaching maturity they produce an atom, often microscopic, similar to that which gave them their own existence, and which in like manner is capable of developing another independent organism; after a time they decline, and at a period fixed within narrow limits they terminate their existence in death.

Such are the characters by which organised beings are distinguished. Characters equally distinctive separate the two great kingdoms into which the organised world is divided. It is true that at the extreme limit of the two kingdoms the distinctness of the boundary line is lost. Nature does not make leaps. The transition from the animal to the vegetable kingdom is so gradual, that the true place of some few bodies is uncertain; but in general the distinctions are too clear and broad to admit of any degree of doubt.

1. Plants carry on a series of vital actions, which have for their object two purposes, and only two: first, the maintenance of the individual, and secondly, the perpetuation of the species. This circle comprises and completes their life. In an animal two others are added, namely, sensation and voluntary motion. The two first, being common to all organised beings, are called organic; the two latter, being peculiar to animals, are termed animal. These last are also sometimes denominated functions of relation, because they put the individual being in relation with the external world; and as the possession of sensation and voluntary motion imparts an intenser kind of life, gives an animation in which feeling, and action, the result of feeling, play predominant parts, so the animal kingdom is called animate, in contrast to the vegetable, which is said to be inanimate. A plant has but one life, the organic or vegetative; an animal has two lives, the organic and the animal.

2. In order in the more richly endowed being to combine the two lives in harmonious action, it is necessary to make some essential changes in its constitution. It is necessary to invert the position of its vegetative organs. These are external in a plant, internal in an animal.

In a plant all the organs are external; the aërial in the atmosphere, the terrestrial in the earth. But suppose the roots, instead of being thus extended outwards, to be reflected inwards, and therefore contained within the stem and branches, the structure would then resemble that of an animal, where the roots—the absorbents of the food—are all contained in the interior of the body.

Upon the inner surface of a portion of animal intestine, soon after a meal has been taken, countless numbers of vessels are seen spread out full of a white fluid. These vessels are to an animal what its roots are to a plant. In a plant the roots are spread out in the soil. In an animal they are spread out over the inner surface of the alimentary canal.

The plant fixed to one spot must have all its food brought to it, since it cannot move from place to place in search of it. It spreads its roots in the soil, it extends its branches verdant with leaves to the sun, air, and rain. In this manner it is always in contact with its food, and with the physical agents, or stimuli, which enable it to convert its food into nourishment. But the animal endowed with sensation, and with the power of moving from place to place at the impulse of its feeling, could not in this manner be put in contact with its food. The possession of these higher faculties imposed the necessity of modifying the position of its vegetative organs. It became indispensable to reflect its roots inwards, and to provide an internal cavity for the reception of its food, over the surface of which its internal roots might expand. By this contrivance the animal, in the exercise of its faculty of locomotion, is kept as constantly and completely in contact with its food as the plant which is fixed to one spot. Wherever it goes it carries a supply of nutriment about with it, and no change of place interrupts or suspends the contact of its roots with its food. Hence the possession of an internal stomach, in connection with an external aperture or mouth, is a general and distinctive character of an animal. Nor is the value of this distinction lessened, by the uncertainty of the mode of nutrition in certain beings low in the organic scale. The distinction holds with regard to all creatures, whose organisation is sufficiently unequivocal to bring them indubitably within the animal kingdom.

3. The substances which sustain life in the two classes are so widely different, as to afford another fundamental distinction between them. Plants subsist on inorganic substances, which they convert into organic matter; animals, on the matter thus prepared for them. No animal can live on inorganic elements or compounds; it must have organisms, or parts of organisms. Carbonic acid, ammonia, and water, are the essential constituents of the food of plants. The food of animals consists of substances elaborated out of these inorganic compounds, by the vital processes of the plant. Standing on the confines of the organic world, plants absorb inorganic elements, and convert them into organic compounds. They are the creators of organic matter. Animals cannot create such matter. They can appropriate and modify it when formed; they can carry on with it a series of advancing combinations far beyond the powers of plants; but they cannot take a single step in the process, for they cannot take the first, without the previous assistance of the plant.

The vegetable kingdom, then, is a vast laboratory, in unceasing operation, for the creation and elaboration of substances of primary necessity to the existence of animals. With the preparation of this matter plants accomplish the end of their being, and their life terminates; but it is at this point that the life of the animal commences. By this relation between the two kingdoms, the higher orders of beings are saved the first step in the vital series; and, consequently, whatever complication is given to their higher organisation, can be exclusively appropriated to the higher purposes of their being.

4. As there can be no function without an organ, so the addition of the two animal faculties, sensation and voluntary motion, of necessity complicates the structure of the animal body. To the organs for carrying on the organic processes, there must be superadded those which are required for the animal faculties.

Hence the addition of the nervous and muscular systems; and in the entire animal series the complexity of these systems, as we shall see as we advance, becomes progressively greater as the range and energy of the faculties increase. The apparatus of sense is multiplied and elaborated as impressions become acute and varied; the bulk and compactness of the muscle is increased in proportion to the power of its contractions, and the extent of its combinations. The wing of the eagle is as much more developed than the wing of the wren, as its flight is higher, and its speed swifter. The muscles which give to the tiger the rapidity and strength of its spring, possess a more intense organisation than those which slowly move on the tardigrade sloth.

The structure of the brain of man is more complex than that of a fish, as his perceptions are more acute and capable of greater combination, comprehension, and continuity.

Such are some of the more striking distinctions between inorganic and organic bodies, and between the two great classes of organized beings. There are other differences, which will be better understood as we proceed, but those now assigned may suffice to convey a clear conception of the nature of their distinctive characters.

CHAPTER II.

Two distinct lives combined in the animal—Characters of the apparatus of the organic life—Characters of the apparatus of the animal life—Characteristic differences in the action of each—Progress of life—Progress of death.

Of the two sets of functions carried on by living beings, it has been shown, that a plant performs only one, while an animal exercises both. The two lives thus in continual play in the animal, differ from each other as much as the process of vegetation differs from that of thought. Each has its own apparatus and action, and though both are closely united, and work together in perfect harmony, they present, in several interesting circumstances, striking contrasts to each other.

1. In general, in the higher classes of animals, the organs that belong to the apparatus of the organic life are single, and not symmetrical; the organs that belong to the apparatus of the animal life are commonly double, and symmetrical. The heart, stomach, liver, and other instruments by which the organic functions are carried on, are single organs. The figure of each is more or less irregular, so that if a line were carried through their centre, it would not divide them into two equal and corresponding portions. On the contrary, the organs of the animal life are symmetrical. The brain and spinal cord are divisible into two perfectly equal parts. The nerves which go off from them, for the most part, go off in pairs equal in size and similar in distribution. The muscular apparatus of one half of the body is the exact counterpart of that of the other; while the arms, hands, and lower extremities are double, and the organization of one is precisely similar to that of its fellow.

2. In general, the apparatus of the organic life is seated in the interior of the body, while that of the animal life is placed on the external surface. The organic organs are the instruments by which life is maintained. Their action cannot be suspended, even for a short space of time, without the extinction of life. But the animal organs are not so much instruments of life, as means by which a certain relation is established between the living being and external objects. And this difference in their office is the reason of the difference in their position. Life depending on the action of the organic organs, they are placed in the interior of the body; they are fixed firmly in their situation in order that they may not be disturbed by the movements of locomotion; they are enveloped in membranes, covered by muscles, placed under the shelter of bones, and every possible care is taken to secure them from accident and to shield them from violence. Existence not being

immediately dependent on the action of the organs of the animal life, they do not need to be protected from the contact of external objects with extraordinary care, but it is necessary to the performance of their functions that they should be placed at the exterior of the body. And there they are placed, and so placed as to afford a defence to the organic organs. The groundwork of the animal is made the bulwark of the organic life. The muscles, the immediate agents by which motion is effected, and the bones, the fixed points and levers by which that motion acquires precision, rapidity, and power, are so disposed that, while the latter accomplish their primary and essential office in relation to the muscles, they serve a secondary, but scarcely less important office in relation to the internal viscera. The thorax, consisting essentially of the spinal column and ribs, together with the powerful muscles that act upon them, forms a moveable cavity in which are placed the lungs, the heart, and the great trunks of the venous and arterial systems; that is, a main portion of the apparatus of the organic functions of respiration and circulation. The bones and muscles protect the central engine that works the circulation. They also take an active part in the performance of the function of respiration: they, further, afford to the lungs (the chief organ of this function, composed of tender and delicate tissues, easily injured, and the slightest injury perilling life) a free and secure place to act in. The fragile part of the apparatus is defended by the osseous portion of it; the play of the latter being equally essential to the function as that of the former. In like manner, the spinal cord, which is more immediately necessary to organic life than any other organ, inasmuch as it maintains the action of respiration, without which the heart ceases to contract in four minutes, is more carefully protected than the brain itself. It is enclosed in a cavity formed by the dense, strong, moveable bones of the spinal column; it is enveloped in several membranous coverings; and to protect it from contact with the hard substances that defend it, it is hung suspended in water. In a word, it is more carefully protected from injury than any other organ of the body, not excepting the heart itself. So the brain, the central seat of animal life, lodged in the cavity of the cranium, is protected by the compact, strong, bony dome of the skull; but the other organs of animal life, not being vital organs, do not need these strong defences, while they require for the exercise of their proper functions a more external position. Hence the organs of sense, which put us in connection with the external world, render us susceptible of pleasure, and give us notice of the approach of objects capable of exciting pain, are placed where external bodies may be brought most conveniently and completely into contact with them; and where alone they can be efficient as sentinels of the system. For this reason, with the exception of the sense of touch, which though placed especially at the extremities of the fingers, is also diffused over the whole external surface of the frame, all the senses have their several seats in the head, the most elevated part of the body, of an ovoid figure, capable of moving independently of the rest of the fabric, and which, being supported on a pivot, is enabled to describe at least two-thirds of a circle.

Such is the difference in the structure and position of the apparatus of the two lives, but the difference in their action is still more striking.

1. The action of the apparatus of the organic life, when sound, is without consciousness; the object of the action of the apparatus of the animal life is the production of consciousness. The final cause of the first is the maintenance of existence; that of the second, the production of conscious existence. Organic processes go on unceasingly within a sentient being, yet they are as unconscious in character in the animal as in the plant, showing the unity of the great laws of organisation. Consciousness is communicated not by giving sensibility to the organic processes, but by constructing a new apparatus, the sole object of which is to produce and maintain a state of varied and extended consciousness. We do not know when the heart dilates to receive the vital current, nor when it contracts to propel it with renewed impetus through the system, nor when the blood flows to the lungs to give out its useless and noxious particles, nor when the air rushes to the blood to take up those particles, to replace them by others, and thus to purify and renovate the vital fluid. Of these processes we have no more consciousness than has a blade of grass of the motion of the fluids that pervade it. On the other hand, when an external object produces, in a sentient nerve, that change of state which we denote by the words "an impression;" when the sentient nerve transmits this impression to the brain; when the brain is thereby brought into the state of perception, the animal life is in active operation, and percipient or conscious existence takes place. Consciousness does not belong to the organic, it *is* the animal life.

2. The functions of the organic life are performed with uninterrupted continuity; to those of the animal life, rest is indispensable. The action of the heart is unceasing; it takes not, and needs not rest. On it goes for the space of eighty or ninety years, at the rate of a hundred thousand strokes every twenty-four hours, having at every stroke a great resistance to overcome, yet it continues this action for this length of time without intermission. Individual parts of it indeed repose for a moment. The auricles rest while the ventricles contract; and the ventricles repose during the systole of the auricles. But this alternate action they continue night and day without ceasing. Alike incessant is the action of the lungs, which, at measured periods, definitely fixed,

receive pure atmospheric air, and emit a noxious gas generated by the processes of life; and the action of the skin, which is always transpiring and always absorbing; and the action of the nutritive organs, which are always at work to compensate the loss which the system is always sustaining.

Of a continuity of action like this the organs of the animal life are incapable. No voluntary muscle can maintain its action beyond a given time; no effort of the will can keep it in a state of uninterrupted contraction; relaxation must alternate with contraction; and even this alternate action cannot go on long without rest. No organ of sense can continue to receive impression after impression without fatigue. By protracted exercise the ear loses its sensibility to sound, the eye to light, the tongue to savour, and the touch to the qualities of bodies about which it is conversant. The brain cannot carry on its intellectual operations with vigour beyond a certain period; the trains of ideas with which it works become, after a time, indistinct and confused; nor is it capable of reacting with energy until it has remained in a state of rest proportioned to the duration of its preceding activity.

And this rest is sleep. Sleep is the repose of the senses, the rest of the muscles, their support and sustenance. What food is to the organic, sleep is to the animal life. Nutrition can no more go on without aliment, than sensation, thought, and motion without sleep.

But it is the animal life only that sleeps; death would be the consequence of the slumber of the organic life. If, when the brain betook itself to repose, the engine that moves the blood ceased to supply it with its vital fluid, never again would it awake. The animal life is active only during a portion of its existence; the activity of the organic life, with the exception just stated, is never suspended; and in order to endow its organs with the power of continuing this constant action, they are rendered incapable of fatigue: fatigue, on the contrary, is inseparable from the action of the organs of the animal life; fatigue imposes the necessity of rest, rest is sleep, and sleep is renovation.

3. Between all the functions of the organic life there is a close relation and dependence. Without the circulation there can be no secretion; without secretion, no digestion; without digestion, no nutrition; without nutrition, no new supply of circulating matter, and so through the entire circle. But the functions of the animal life are not thus dependent on each other. One of the circle may be disordered without much disturbance of the rest; and one may cease altogether, while another continues in vigorous action. Sensation may be lost, while motion continues; and the muscle may contract though it cannot feel. One organ of sense may sleep while the rest are awake. One intellectual faculty may be in operation while others slumber. The muscle of volition may act, while there is no consciousness of will.

Even the organs of the voice and of progression may perform their office while the sensorium is deeply locked in sleep.

4. The two lives are born at different periods, and the one is in active operation before the other is even in existence. The organic is not only anterior to the animal, but it is by the action of the organic that existence is given to the animal life. The organic life is born at the first moment of existence; the animal life does not exist functionally until a period comparatively distant; the epoch emphatically called the period of birth, namely, the period when the new being is detached from its mother; when it first comes into contact with external objects; when it carries on all the functions of its economy by its own organs, and consequently enjoys independent existence.

5. The functions of the organic life are perfect at once. The heart contracts, the arteries secrete, and the respiratory organs work as well the first moment they begin to act as at any subsequent period. They require no teaching from experience, and they profit nothing from its lessons. On the contrary, the operations of the brain, and the actions of the voluntary muscles, feeble and uncertain at first, acquire strength by slow degrees, and attain their ultimate perfection only at the adult age. How indistinct and confused are the first sensations of the infant! Before it acquires accuracy, precision, and truth, how immense the labour spent upon perception! Sensations are succeeded by ideas; sensations and ideas coalesce; combinations thus formed suggest others previously united, and these a third, and the third a fourth, and so is constituted a continuous train of thought. But the infantile associations between sensation and sensation, between idea and idea, and between sensations and ideas, are, to a certain extent, incorrect, and to a still greater extent inadequate; and the misconception necessarily resulting from this early imperfection in the intellectual operations, is capable of correction only by subsequent and more extended impressions. During its waking hours, a large portion of the time of the infant is spent in receiving impressions which come to it every instant from all directions, and which it stores up in its little treasury; but a large portion is also consumed in the far more serious and difficult business of discrimination and correction. Could any man, after having attained the age of manhood, reverse the order of the course through which he has passed; could he, with the power of observation, together with the experience that belong to manhood, retrace with perfect exactness every step of his sentient existence, from the age of forty to the moment that the air first came into contact with his body at the moment of his leaving his maternal dwelling, among the truths he would learn, the most interesting, if not the most surprising, would be those which relate to the manner in which he dealt with his earliest impressions; with

the mode in which he combined them, recalled them, laid them by for future use; made his first general deduction; observed what subsequent experience taught to be conformable, and what not conformable, to this general inference; his emotions on detecting his first errors, and his contrasted feelings on discovering those comprehensive truths, the certainty of which became confirmed by every subsequent impression. Thus to live backwards would be, in fact, to go through the analysis of the intellectual combinations, and, consequently, to obtain a perfect insight into the constitution of the mind; and among the curious results which would then become manifest, perhaps few would appear more surprising than the true action of the senses. The eye, when first impressed by light, does not perceive the objects that reflect it; the ear, when first impressed by sound, does not distinguish the sonorous body. When the operation for cataract has been successfully performed in a person born blind, the eye immediately becomes sensible to light, but the impression of light does not immediately give information relative to the properties of bodies. It is gradually, not instantaneously; it is even by slow degrees that luminous objects are discerned with distinctness and accuracy. To see, to hear, to smell, to taste, to touch, are processes which appear to be performed instantaneously, and which actually are performed with astonishing rapidity in a person who observes them in himself; but they were not always performed thus rapidly: they are processes acquired, businesses learnt; processes and businesses acquired and learnt, not without the cost of many efforts and much labour. But the senses afford merely the materials for the intellectual operations of memory, combination, comparison, discrimination, induction, operations the progress of which is so slow, that they acquire precision, energy, and comprehensiveness only after the culture of years.

And the same is true of the muscles of volition. How many efforts are made before the power of distinct articulation is acquired! how many before the infant can stand! how many before the child can walk! The organic life is born perfect; the animal life becomes perfect only by servitude, and the aptitude which service gives.

6. The organic life may exist after the animal life has perished. The animal life is extinguished when sensation is abolished, and voluntary motion can be performed no more. But disease may abolish sensation and destroy the power of voluntary motion, while circulation, respiration, secretion, excretion, in a word, the entire circle of the organic functions continues to be performed. Apoplexy may reduce to fatuity the most exalted intellect, and render powerless and motionless muscles of the greatest strength; while the action of the heart and the contractions of the involuntary muscles may not only not be weakened, but may act with preternatural energy. Apoplexy may even

completely extinguish the animal life, and yet the organic may go on for hours, days, and even weeks; while catalepsy, one of the most singular diseases to which the human frame is subject, may wholly abolish sensation and volition, while it may impart to the voluntary muscles the power of contracting with such unnatural energy and continuity, that the head, the trunk, the limbs may become immoveably fixed in whatever attitude they happen to be at the moment the paroxysm comes on. In this extraordinary condition of the nervous system, however long the paroxysm last, and however complete the abolition of consciousness, the heart continues to beat, and the pulse to throb, and the lungs to respire, and all the organic organs to perform their ordinary functions. Dr. Jebb gives the following description of the condition of a young lady who was the subject of this curious malady.

"My patient was seized with an attack just as I was announced. At that moment she was employed in netting; she was in the act of passing the needle through the mesh; in that position she became immoveably rigid, exhibiting, in a pleasing form, a figure of death-like sleep, beyond the power of art to imitate, or the imagination to conceive. Her forehead was serene, her features perfectly composed. The paleness of her colour, and her breathing, which at a distance was scarcely perceptible, operated in rendering the similitude to marble more exact and striking. The position of her fingers, hands, and arms was altered with difficulty, but preserved every form of flexure they acquired: nor were the muscles of the neck exempted from this law, her head maintaining every situation in which the hand could place it, as firmly as her limbs."

In this condition of the system the senses were in a state of profound sleep; the voluntary muscles, on the contrary, were in a state of violent action; but this action not being excited by volition, nor under its control, the patient remained as motionless as she was insensible. The brain was in a state of temporary death; the muscle in a state of intense life. And the converse may happen: the muscle may die, while the brain lives; contractility may be destroyed, while sensibility is perfect; the power of motion may be lost, while that of sensation may remain unaffected. A case is on record, which affords an illustration of this condition of the system. A woman had been for some time confined to her bed, labouring under severe indisposition. On a sudden she was deprived of the power of moving a single muscle of the body; she attempted to speak, but she had no power to articulate; she endeavoured to stretch out her hand, but her muscles refused to obey the commands of her will, yet her consciousness was perfect, and she retained the complete possession of her intellectual faculties. She perceived that her attendants thought her dead, and was conscious of the performance upon her own person of the services usually paid to the dead; she was laid out, her toes were bound together, her chin was tied up; she heard the arrangements for her funeral discussed, and yet she was unable to make the slightest sign that she was still in the possession of sense, feeling, and life.

In one form of disease, then, the animal life, both the sensitive and the motive portions of it, may perish; and in another, either part of it may be suspended, while the organic life continues in full operation: it follows that the two lives, blended as they are, are distinct, since the one is capable of perishing without involving the destruction of the other.

7. And, finally, as the organic life is the first born, so it is the last to die; while the animal life, as it is the latest born, and the last to attain its full development, so it is the earliest to decline and the first to perish. In the process of natural death, the extinction of the animal is always anterior to that of the organic life. Real death is a later, and sometimes a much later event than apparent death. An animal appears to be dead when, together with the abolition of sensation and the loss of voluntary motion, respiration, circulation, and the rest of the organic functions can no longer be distinguished; but these functions go on some time after they have ceased to afford external indications of their action. In man, and the warm-blooded animals in general, suspension or submersion extinguishes the animal life, at the latest, within the space of four minutes from the time that the atmospheric air is completely excluded from the lungs; but did the organic functions also cease at the same period, it would be impossible to restore an animal to life after apparent death from drowning and the like. But however complete and protracted the abolition of the animal functions, reanimation is always possible as long as the organic organs are capable of being restored to their usual vigour. The cessation of the animal life is but the first stage of death, from which recovery is possible; death is complete only when the organic together with the animal functions have wholly ceased, and are incapable of being re-established.

In man, the process of death is seldom altogether natural. It is generally rendered premature by the operation of circumstances which destroy life otherwise than by that progressive and slow decay which is the inevitable result of the action of organized structure. Death, when natural, is the last event of an extended series, of which the first that is appreciable is a change in the animal life and in the noblest portion of that life. The higher faculties fail in the reverse order of their development; the retrogression is the inverse of the progression, and the noblest creature, in returning to the state of non-existence, retraces step by step each successive stage by which it reached the summit of life.

In the advancing series, the animal is superadded to the organic life; sensation, the lowest faculty of the animal life, precedes ratiocination, the highest. The senses called into play at the moment of birth soon acquire the utmost perfection of which they are capable; but the intellectual faculties, later developed, are still later perfected, and the highest the latest.

In the descending series, the animal life fails before the organic, and its nobler powers decay sooner and more rapidly than the subordinate. First of all, the impressions which the organs of sense convey to the brain become less numerous and distinct, and consequently the material on which the mind operates is less abundant and perfect; but at the same time, the power of working vigorously with the material it possesses more than proportionally diminishes. Memory fails; analogous phenomena are less readily and less completely recalled by the presence of those which should suggest the entire train; the connecting links are dimly seen or wholly lost; the train itself is less vivid and less coherent; train succeeds train with preternatural slowness, and the consequence of these growing imperfections is that, at last, induction becomes unsound just as it was in early youth; and for the same reason, namely, because there is not in the mental view an adequate range of individual phenomena; the only difference being that the range comprehended in the view of the old man is too narrow, because that which he had learnt he has forgotten; while in the youth it is too narrow, because that which it is necessary to learn has not been acquired.

And with the diminution of intellectual power the senses continue progressively to fail: the eye grows more dim, the ear more dull, the sense of smell less delicate, the sense of touch less acute, while the sense of taste immediately subservient to the organic function of nutrition is the last to diminish in intensity and correctness, and wholly fails but with the extinction of the life it serves.

But the senses are not the only servants of the brain; the voluntary muscles are so equally; but these ministers to the master-power, no longer kept in active service, the former no longer employed to convey new, varied, and vivid impressions, the latter no longer employed to execute the commands of new, varied, and intense desires, become successively feebler, slower, and more uncertain in their action. The hand trembles, the step totters, and every movement is tardy and unsteady. And thus, by the loss of one intellectual faculty after another, by the obliteration of sense after sense, by the progressive failure of the power of voluntary motion; in a word, by the declining energy and the ultimate extinction of the animal life, man, from the state of maturity, passes a second time through the stage of childhood back to that of infancy; lapses even into the condition of the embryo: what the fœtus was, the man of extreme old age is: when he began to exist, he possessed only organic life; and before he is ripe for the tomb, he returns to the condition of the plant.

And even this merely organic existence cannot be long maintained. Slow may be the waste of the organic organs; but they do waste, and that waste is not repaired, and consequently their functions languish, and no amount of stimulus is capable of invigorating their failing action. The arteries are rigid and cannot nourish; the veins are relaxed and cannot carry on the mass of blood that oppresses them; the lungs, partly choked up by the deposition of adventitious matter, and partly incapable of expanding and collapsing by reason of the feeble action of the respiratory apparatus, imperfectly aërate the small quantity of blood that flows through them; the heart, deprived of its wonted nutriment and stimulus, is unable to contract with the energy requisite to propel the vital current; the various organs, no longer supplied with the quantity and quality of material necessary for carrying on their respective processes, cease to act; the machinery stops, and this is death.

And now the processes of life at an end, the body falls within the dominion of the powers which preside universally over matter; the tie that linked all its parts together, holding them in union and keeping them in action, in direct opposition to those powers dissolved, it feels and obeys the new attractions to which it has become subject; particle after particle that stood in beautiful order fall from their place; the wonderful structures they composed melt away; the very substances of which those structures were built up are resolved into their primitive elements; these elements, set at liberty, enter into new combinations, and become constituent parts of new beings; those new beings in their turn perish; from their death springs life, and so the changes go on in an everlasting circle.

As far as relates to the organised structures in which life has its seat, and to the operations of life dependent on those structures, such is its history; a history not merely curious, but abounding with practical suggestions of the last importance. The usefulness of a familiar acquaintance with the phenomena which have now been elucidated will be apparent at every step as we proceed.

CHAPTER III.

Ultimate object of organisation and life—Sources of pleasure—Special provision by which the organic organs influence consciousness and afford pleasure—Point at which the organic organs cease to affect consciousness, and why—The animal appetites: the senses: the intellectual faculties: the selfish and sympathetic affections: the moral and religious faculties—Pleasure the direct, the ordinary, and the gratuitous result of the action of the organs—Pleasure conducive to the development of the organs, and to the continuance of their action—Progress of human knowledge—Progress of human happiness.

The object of structure is the production of function. Of the two functions combined in the living animal, one is wholly subservient to the other. To build up the apparatus of the animal life, and to maintain it in a condition fit for performing its functions, is the sole object of the existence of the organic life. What then is the object of the animal life? That object, whatever it be, must be the ultimate end of organisation, and of all the actions of which it is the seat and the instrument.

Two functions, sensation and voluntary motion, are combined in the animal life; of these the latter is subservient to the former: voluntary motion is the servant of sensation, and exists only to obey its commands.

Is sensation, then, the ultimate object of organisation? Simple sensation cannot be an ultimate object, because it is invariably attended with a further result; for sensation is either pleasurable or painful. Every sensation terminates in a pleasure or a pain. Pleasure or pain, the last event in the series, must then be the final end.

All sentient beings are thus placed under the dominion of two great powers, pleasure and pain. During every moment of consciousness they are under the influence of one or the other of these powers. We cannot conceive of a sentient being who, as long as he is sentient, is not, in a greater or less degree, either enjoying or suffering. The state of pleasure or of pain, then, being that in which every other state of consciousness terminates, must be the ultimate object of sentient existence.

Is a state of pain the ultimate object designed and secured? Is this state the ordained and the actual result of the action of sentient organs? That cannot be; for the production of pain is the indirect, never the direct, the extraordinary, never the ordinary, result of the actions of life. It is clear therefore that the dominion over sentient existence is not given to pain: it must then have been assigned to pleasure the opposite power, for there is no other of which it is possible to conceive.

The end of organic existence is animal or sentient existence; the end of sentient existence is pleasurable existence; the end of life therefore is not simple consciousness, but pleasurable consciousness; not mere being, but well-being; in other words, such a state as we commonly express by the phrases "a state of pleasure" or "a state of enjoyment;" and it is in this sense that these words are here employed throughout, the term "pleasure" being used as opposed to "pain," and "enjoyment" as opposed to "suffering."

It is affirmed, then, that every organ in the animal body is so constructed as to bring about, directly or indirectly, a state of pleasurable consciousness or well-being; that to this object the action of every organ is subservient, and that in this every such action, when natural and sound, ultimately terminates.

No other evidence of this is necessary than the fact, if it can be established as a fact, that, in the entire sentient creation, the higher the organised structure the greater is the range of function; and, as an invariable consequence, the higher and more varied becomes the enjoyment, mediately or immediately, connected with it. From its most simple to its most complex state every successive addition to structure, by which function is elevated and made more perfect, proportionally increases the exquisiteness of the pleasure to which the function ministers, and in which it terminates.

Such is the constitution of the animal organisation that—

Pleasure is the result of the action of living organs.

Pleasure is the direct, the ordinary and the gratuitous result of their action.

Pleasure is conducive to their complete development, and thereby to the increase of their capacity for affording enjoyment.

Pleasure is equally conducive to the perpetuation of their actions, and consequently to the maintenance of life.

It follows not only that enjoyment is the end of life, but that it is the means by which life is prolonged.

Of the truth of each of these propositions it will be interesting to contemplate the plenitude of the proof.

1. In the first place, pleasure is the result of the action even of the organic organs, although it has been shown that one character by which they are distinguished is, that they are unattended with consciousness. How, then, can they be the sources of pleasure? By a special provision, consciousness is indirectly connected with the processes of this class, limited in extent indeed, and uniformly terminating at a certain point, but the extent and the limitation alike conducing to the pleasurableness of its nature. And this is an

adjustment in the constitution of our frame which is well deserving of attention.

The principal organs by which the organic processes are performed, are placed in the cavities of the chest and abdomen. They are presided over by that portion of the nervous system which is termed the ganglionic, or organic system. Among the peculiarities of this system, one of the most remarkable is, that it is, in itself, destitute of feeling. Sensibility is inseparably associated with the idea commonly formed of a nerve. But the nervous system consists of two portions; one presiding over sensation and voluntary motion, hence called the sentient and motor portion; the other destitute of sensation, but presiding over all the movements by which the organic processes are carried on, hence called the organic portion. The influence of the organic nerves is essential to the organic processes. If the communication between an organic nerve and an organ be interrupted, the function of the organ, whatever it be, is arrested. Without its organic nerves the stomach cannot secrete gastric juice; the consequence is, the aliment is undigested. Without its organic nerves the liver cannot secrete bile ; the consequence is, that the process of digestion stops, and the nutritive part of the aliment is incapable of being separated from its excrementitious portion. The organic nerves encompass the great trunks of the blood-vessels that convey the material of nutriment, that is, arterial blood, to the organs. In all its ramifications through an organic organ, an arterial vessel is accompanied by its organic nerves, so that, wherever the arterial capillary branch goes, secreting and nourishing, there goes, inseparably united with it, an organic nerve, exciting and governing.

But this nerve neither feels nor communicates feeling; hence it can impart no consciousness to the operation of any process dependent upon it. Yet there is not one of these processes that does not exert, during every moment we are awake, an influence over consciousness. How? By a special process, as curious in its nature as it is important in its result.

Branches of sentient nerves are transmitted from the animal to the organic system, and from the organic to the animal; and an intimate communication is established between the two classes. The mode in which this communication is effected is clearly shown by the communicating branches that unite the two great nervous centres, the sentient and the non-sentient. Each sentient (spinal) nerve before it goes out to the animal organs, to which it is destined to communicate sensation, sends off two branches to each ganglion of the sympathetic or organic (non-sentient) system. Branches are equally sent off from the ganglionic to the spinal system. The sentient mix and mingle with the insentient nerves, accompany them in their course to the organic organs, and ramify with them throughout their substance. It is manifest, then, that sentient nerves, nerves not necessary to the organic processes, having, as far as is known, nothing whatever to do with those processes, enter as constituent parts into the composition of the organic organs. What is the result? That organic organs are rendered sentient; that organic processes, in their own nature insensible, become capable of affecting consciousness. What follows? What is the consciousness excited? Not a consciousness of the organic process. Of that we still remain wholly insensible. Not simple sensation. The result uniformly produced, as long as the state of the system is that of health, is pleasurable consciousness. The heart sends out to the organs its vital current. Each organ, abstracting from the stream the particles it needs, converts them into the peculiar fluid or solid it is its office to form. The stomach, from the arterial streamlets circulating through it, secretes gastric juice; the liver, from the venous streamlets circulating through it, secretes bile. When these digestive organs have duly prepared their respective fluids, they employ them in the elaboration of the aliment. We are not conscious of this elaboration, though it goes on within us every moment; but is consciousness not affected by the process? Most materially. Why? Because sentient mingle with organic nerves; because the sentient nerves are impressed by the actions of the organic organs. And how impressed? As long as the actions of the organic organs are sound, that is, as long as their processes are duly performed, the impression communicated to the sentient nerves is in its nature agreeable; is, in fact, THE PLEASURABLE CONSCIOUSNESS WHICH CONSTITUTES THE FEELING OF HEALTH. The state of health is nothing but the result of the due performance of the organic organs: it follows that the feeling of health, the feeling which is ranked by every one among the most pleasurable of existence, is the result of the action of organs of whose direct operations we are unconscious. But the pleasurable consciousness thus indirectly excited is really the consequence of a special provision, established for the express purpose of producing pleasure. Processes, in their own nature insensible, are rendered sentient expressly for this purpose, that, over and above the special object they serve, they may afford enjoyment. In this case the production of pleasure is not only altogether gratuitous, not only communicated for its own sake, not only rested in as an ultimate object, but it is made to commence at the very confines of life; it is interwoven with the thread of existence; it is secured in and by the actions that build up and that support the very frame-work, the material instrument of our being.

But if the communication of sensibility to processes in their own nature incapable of exciting feeling, for the purpose of converting them into sources of pleasurable consciousness, indicate an express provision for the production of enjoyment, that provision is no less exemplified in the point at which this superadded sensibility is made to cease.

Some of the consequences of a direct communication of consciousness to an organic process have been already adverted to. Had the eye, besides transmitting rays of light to the optic nerve, been rendered sensible of the successive passage of each ray through its substance, the impression excited by luminous bodies, which is indispensable to vision, the ultimate object of the instrument, if not wholly lost, must necessarily have become obscure, in direct proportion to the acuteness of this sensibility. The hand of the musician could scarcely have executed its varied and rapid movements upon his instrument, had his mind been occupied at one and the same instant with the process of muscular contraction in the finger, and the idea of music in the brain. Had the communication of such a twofold consciousness been possible, in no respect would it have been beneficial, in many it would have been pernicious; and the least of the evils resulting from it would have been, that the inferior would have interrupted the superior faculty, and the means deteriorated the end. But in some cases the evil would have been of a much more serious nature. Had we been rendered sensible of the flow of the vital current through the engine that propels it; were the distension of the delicate heart-valves that direct the current ever present to our view; by some inward feeling were we reminded, minute by minute, of the progress of the aliment through the digestive apparatus, and were the mysterious operations of the organic nerves palpable to sight, the terror of the maniac, who conceived that his body was composed of unannealed glass, would be the ordinary feeling of life. Every movement would be a matter of anxious deliberation; and the approach of every body to our own would fill us with dismay. But adjusted as our consciousness actually is, the point at which the organic process begins is that at which sensation ends. Had sensation been extended beyond this point, it would have been productive of pain: at this point it uniformly stops. Nevertheless, by the indirect connexion of sensation with the organic processes, a vast amount of pleasure might be created: a special apparatus is constructed for the express purpose of establishing the communication. There is thus the twofold proof, the positive and the negative, the evidence arising as well from what they do, as from what they abstain from doing, that the organic processes are, and are intended to be, sources of enjoyment.

But the production of pleasure, commencing at this the lowest point of conscious existence, increases with the progressive advancement of organization and function.

The appetite for food, and the voluntary actions dependent upon it, may be considered as the first advancement beyond a process purely organic. The function by which new matter is introduced into the system and converted into nutriment, is partly an animal, and partly an organic operation. The animal part of it consists of the sensations of hunger and thirst, by which we are taught when the wants of the system require a fresh supply of aliment, together with the voluntary actions by which the aliment is introduced into the system. The organic part of the function consists of the changes which the aliment undergoes after its introduction into the system, by which it is converted into nutriment. Sensations always of a pleasurable nature arise indirectly in the manner already explained, from the due performance of the organic part of the function; but pleasure is also directly produced by the performance of the animal part of it. Wholesome food is grateful; the satisfaction of the appetite for food is pleasurable. Food is necessary to the support of life; but it is not indispensable to the maintenance of life that food should be agreeable. Appetite there must be, that food may be eaten; but the act of eating might have been secured without connecting it with pleasure. Pleasure, however, is connected with it, first directly, by the gratefulness of food, and secondly indirectly, by the due digestion of the food. And the annexation of pleasure in this twofold mode to the performance of the function of nutrition is another case of the gratuitous bestowment of pleasure; another instance in which pleasure is communicated for its own sake, and rested in as an ultimate object. Pleasures of this class are sometimes called low; they are comparatively low; but they are not the less pleasures, because they are exceeded in value by pleasures of a nobler nature. Man may regard them with comparative indifference, because he is endowed with faculties which afford him gratifications superior in kind and larger in amount; but it is no mark of wisdom to despise and neglect even these: for they are annexed to the exercise of a function which is the first to exalt us above a merely organic existence; they are the first pleasures of which, considered merely as sentient creatures, we are susceptible; they amount in the aggregate to an immense sum; and they mark the depth in our nature in which are laid the fountains of enjoyment.

Organs of sense, intellectual faculties, social affections, moral powers, are superadded endowments of a successively higher order: at the same time, they are the instruments of enjoyment of a nature progressively more and more exquisite.

An organ of sense is an instrument composed of a peculiar arrangement of organized matter, by which it is adapted to receive from specific agents definite impressions. Between the agent that produces and the organ that receives the impression, the adaptation is such, that the result of their mutual action is, in the first place, the production of sensation, and, in the second place, the production of pleasure. The pleasure is as much the result as the sensation. This is true of the eye in seeing, the ear in hearing, the hand in touching, the organ of smell in smelling, and the tongue in tasting. Pleasure is linked with the sense; but there might have been the sense without the pleasure. A slight difference in the construction of the organ, or in the intensity of the agent, would not merely have changed, it would even have reversed the result; would have rendered the habitual condition of the eye, the ear, the skin, not such as it now is in health, but such as it is in the state of inflammation. But the adjustment is such as habitually to secure that condition of the system in which every action that excites sensation produces pleasure as its ordinary concomitant; and the amount of enjoyment which is thus secured to every man, and which every man actually experiences in the ordinary course of an ordinary life, it would be beyond his power to estimate were he always sensible of the boon; but the calculation is altogether impossible, when, as is generally the case, he merely enjoys without ever thinking of the provisions by which he enjoys.

But if the pleasures that arise from the ordinary operations of sense form, in the aggregate, an incalculable sum, how great is the accession brought to this stock by the endowments next in order in the ascending scale, namely, the intellectual faculties!

There is one effect resulting from the operation of the intellectual faculties on the senses that deserves particular attention. The higher faculties elevate the subordinate in such a manner as to make them altogether new endowments. In illustration of this, it will suffice to notice the change wrought, as if in the very nature of sensation, the moment it becomes combined with an intellectual operation, as exemplified in the difference between the intellectual conception of beauty, and the mere perception of sense. The grouping of the hills that bound that magnificent valley which I behold at this moment spread out before my view; the shadow of the trees at the base of some of them, stretching its deep and varied outline up the sides of others; the glancing light now brightening a hundred different hues of green on the broad meadows, and now dancing on the upland fallows; the ever-moving, ever-changing clouds; the scented air; the song of birds; the still more touching music which the breeze awakens in the scarcely-trembling branches of those pine-trees,—the elements of which this scene is composed, the mere objects of sense, the sun, the sky, the air, the hills, the woods, and the sounds poured out from them, impress the senses of the animals that graze in the midst of them; but on their senses they fall dull and emotionless, exciting no perception of their loveliness, and giving no taste of the pleasures they are capable of affording. Nor even in the human being, whose intellectual faculties have been uncultivated, do they awaken either emotions or ideas; the clown sees them, hears them, feels them scarcely more than the herds he tends: yet in him whose mind has been cultivated and unfolded, how numerous and varied the impressions, how manifold the combinations, how exquisite the pleasures they produce!

And from the more purely intellectual operations, from memory, comparison, analysis, combination, classification, induction, how still nobler the pleasure! Not to speak of the happiness of him who, by his study of natural phenomena, at length arrived at the stupendous discovery that the earth and all the stars of the firmament move, and that the feather falls to the ground, by the operation of one and the same physical law; nor of the happiness of him who sent his kite into the cloud, and brought down from its quiet bed the lightning which he suspected was slumbering there; nor of the happiness of him who concentrated, directed, and controlled that mighty power which has enabled the feeble hand of man to accomplish works greater than have been feigned of fabled giant; which has annihilated distance; created, by economising, time; changed in the short space in which it has been in operation the surface of the habitable globe; and is destined to work upon it more and greater changes than have been effected by all other causes combined; nor of the happiness of him who devoted a longer life with equal success to a nobler labour, that of REARING THE FABRIC OF FELICITY BY THE HAND OF REASON AND OF LAW;—in the ordinary intellectual operations of ordinary men, in their ordinary occupations, there is happiness. The intellectual pleasures of such men as Newton, Franklin, Watt, and Bentham, can be *equalled* only by those who possess equal intellectual power, and who put forth equal intellectual energy: to be greatly happy, as they were, it were necessary to be as highly endowed; but to be happy, it is not necessary to be so endowed. Every human being whose moments have passed with winged speed, whose day has been short, whose year is gone almost as soon as it seemed commenced, has derived from the exercise of his intellectual faculties pleasures countless in number and inestimable in value.

But the sympathetic pleasures, out of which grow the social, are of a still higher order even than the intellectual. The pleasures that result from the action of the organic organs, from the exercise of the several senses, and from the operation of the intellectual faculties, like the sensations in which they arise, belong exclusively to the individual being that experiences them, and cannot be communicated to another. Similar sensations and pleasures may be felt by beings similarly constituted; but the actual sensations and pleasures afforded by the exercise of a person's own organs and faculties, are no more capable of becoming another's than his existence. These, then, are strictly the selfish pleasures; and the provision that has been made for securing them has been shown.

But there are pleasures of another class, pleasures having no relation whatever to a person's own sensation or happiness; pleasures springing from the perception of the enjoyment of others. The sight of pleasure, not its own, affects the human heart, provided its state of feeling be natural and sound, just as it would be affected were it its own. Not more real is the pleasure arising from the gratification of appetite, the exercise of sense, and the operation of intellect, than that arising from the consciousness that another sentient being is happy. Pleasures of this class are called sympathetic, in contradistinction to those of the former class, which are termed selfish.

There are then two principles in continual operation in the human being, the selfish and the sympathetic. The selfish is productive of pleasure of a certain kind; the sympathetic is productive of pleasure of another kind. The selfish is primary and essential; the sympathetic, arising out of the selfish, is superadded to it. And so precisely what the animal life is to the organic, the sympathetic principle is to the selfish; and just what the organic life gains by its union with the animal, the mental constitution gains by the addition of the sympathetic to the selfish affection. The analogy between the combination in both cases is in every respect complete. As the organic life produces and sustains the animal, so the sympathetic principle is produced and sustained by the selfish. As the organic life is conservative of the entire organization of the body, so the selfish principle is conservative of the entire being. As the animal life is superadded to the organic, extending, exalting, and perfecting it, so the sympathetic principle is superadded to the selfish, equally extending, exalting, and perfecting it. The animal life is nobler than the organic, whence the organic is subservient to the animal; but there is not only no opposition, hostility, or antagonism between them, but the strictest possible connexion, dependence, and subservience. The sympathetic principle is nobler than the selfish, whence the selfish is subservient to the sympathetic; but there is not only no opposition, hostility, or antagonism between them, but the strictest possible connexion, dependence, and subservience. Whatever is conducive to the perfection of the organic, is equally conducive to the perfection of the animal life; and whatever is conducive to the attainment of the true end of the selfish, is equally conducive to the attainment of the true end of the sympathetic principle. The perfection of the animal life cannot be promoted at the expense of the organic, nor that of the organic at the expense of the animal; neither can the ultimate end of the selfish principle, be secured by the sacrifice of the sympathetic, nor that of the sympathetic, by the sacrifice of the selfish. Any attempt to exalt the animal life beyond what is compatible with the healthy state of the organic, instead of accomplishing that end, only produces bodily disease. Any attempt to extend the selfish principle beyond what is compatible with the perfection of the sympathetic, or the sympathetic beyond what is compatible with the perfection of the selfish, instead of accomplishing the end in view, only produces mental disease. Opposing and jarring actions, antagonizing and mutually destructive powers, are combined in no other work of nature; and it would be wonderful indeed were the only instance of it found in man, the noblest of her works, and in the mind of man, the noblest part of her noblest work.

No one supposes that there is any such inharmonious combination in the organisation of his physical frame, and the notion that it exists in his mental constitution, as it is founded in ignorance, so it is productive of mischief. In both, indeed, are manifest two great powers, each distinct; each having its own peculiar operation; and the one being subservient to the other, but both conducing alike to one common end. By the addition of the apparatus of the animal to that of the organic life, a nobler structure is built up than could have been framed by the organic alone: by the addition of the sympathetic to the selfish part of the mental constitution, a happier being is formed than could have been produced by the selfish alone. And as the organic might have existed without the animal life, but by the addition of the animal a new and superior being is formed, so might the selfish part of the mental constitution, and the pleasures that flow from it, have existed alone; but by the addition of the sympathetic, a sum is added to enjoyment, of the amount of which some conception may be formed by considering what human life would be, with every selfish appetite and faculty gratified in the fullest conceivable degree, but without any admixture whatever of sympathetic or social pleasure. Selfish enjoyment is not common. If any one set himself to examine what at first view might seem a purely selfish pleasure, he will soon be sensible that, of the elements composing any given state of mind to which he would be willing to affix the term pleasurable, a vast preponderance consists of sympathetic associations. The more accurately he examine, and the farther he carry his analysis, the stronger will become his conviction, that a purely selfish enjoyment, that is, a truly pleasurable state of mind, in no degree, mediately or immediately, connected with the pleasurable state of another mind, is exceedingly rare.

But if the constitution of human nature and the structure of human society alike render it difficult for the human heart to be affected with a pleasure in no degree derived from—absolutely and totally unconnected with sympathetic association, of that complex pleasure which arises out of social intercourse, partly selfish and partly sympathetic, how far sweeter the sympathetic than the selfish; and as the sympathetic preponderates over the selfish, how vast the increase of the pleasure! And when matured, exalted into affection—affection, that holy emotion which exerts a transforming influence over the selfish part of human nature, turning it into the sympathetic; affection, which renders the happiness of the beloved object dearer to the heart than its own; affection, among the benignant feelings of which as there is none sweeter so there is none stronger than that of self-devotion, nay, sometimes even of self-sacrifice; affection, which is sympathy pure, concentrated, intense—Oh how beautiful is the constitution of this part of our nature, by which the most transporting pleasures the heart receives are the direct reflection of those it gives!

Nor ought it be overlooked, that, while nearly all the selfish, like all the sensual pleasures, cannot be increased beyond a fixed limit, cannot be protracted beyond a given time, are short-lived in proportion as they are intense, and satiate the appetite they gratify, the sympathetic pleasures are capable of indefinite augmentation; are absolutely inexhaustible; no limit can be set to their number, and no bound to their growth; they excite the appetite they gratify; they multiply with and by participation, and the more is taken from the fountain from which they flow, the deeper, the broader, and the fuller the fountain itself becomes.

But not only is the mental state of affection in all its forms and degrees highly pleasurable, but the very consciousness of being the object of affection is another pleasure perfectly distinct from that arising immediately from the affection itself. It has been said of charity, that it is twice blessed, that it blesses alike him that gives and him that receives; but love has in it a threefold blessing: first, in the mental state itself; secondly, in the like mental state which the manifestation of it produces in another; and thirdly, in the mental state inseparable from the consciousness of being the object of affection. And this reflex happiness, this happiness arising from the consciousness of being the object, is even sweeter than any connected with being the subject of affection.

In like manner there is pleasure in the performance of beneficent actions; in energetic, constant, and therefore ultimately successful exertions to advance the great interests of human kind, in art, in science, in philosophy, in education, in morals, in legislation, in government; whether those exertions are put forth in the study, the school, the senate, or any less observed though perhaps not less arduous nor less important field of labour. Exertions of this kind beget in those for whom, towards those by whom, they are made, benignant feelings —respect, veneration, gratitude, love. With such feelings the philosopher, the instructor, the legislator, the statesman, the philanthropist, knows that he is, or that, sooner or later, he will be regarded by his fellow-men; and in this consciousness there is happiness: but this is another source of happiness perfectly distinct from that arising from the performance of beneficent actions; it is a new happiness superadded to the former, and, if possible, still more exquisite. Thus manifold is the beneficent operation of the sympathetic affection: thus admirable is the provision made in the constitution of our nature for the excitement and extension of this affection, and, through its instrumentality, for the multiplication and exaltation of enjoyment!

In affections and actions of this class, and in the pleasures that result from them, there is much of the nature which is commonly termed moral. The moral faculty is the power to regulate voluntary conduct by a prescribed rule, from a given motive. The rule is the moral code, whatever that may be; the motive is that which induces obedience to the rule, as praise or blame, reward or punishment. On the power thus to regulate his conduct, a power possessed by no other creature but man, are based law and government. It is by the operation of this power that he is capable of obedience to law, and that he can become the subject of government. This power of his nature is higher than any of the preceding, for it is their regulator and guide; it is that by which they attain their proper and ultimate object.

Of whatever pleasure human nature is capable in sensation, in idea, in appetite, in passion, in emotion, in affection, in action; whatever is productive of real pleasure, in contradistinction to what only cheats with the false hope of pleasure; whatever is productive of pure pleasure, in contradistinction to what is productive partly of pleasure and partly of pain, and consequently productive not of pure, but of mixed pleasure; whatever is productive of a great degree of pleasure in contradistinction to what is productive of a small degree of pleasure; whatever is productive of lasting pleasure, in contradistinction to what is productive of temporary pleasure; whatever is productive of ultimate pleasure, in contradistinction to what is productive of immediate pleasure, but ultimate pain; this greatest and most perfect pleasure it is the part of the moral faculty to discover. In the degree in which the operation of this faculty is correct and complete, it enables the human being to derive from every faculty of his nature the greatest, the purest, the most enduring pleasure; that is, the maximum of felicity. This is the proper scope and aim of the moral faculty; to this its right exercise is uniformly conducive; and this, as it is better cultivated and directed, it will accomplish in a higher degree, in a continual progression, to which no limit can be assigned.

But if the proper operation of this faculty be to render every other in the highest degree conducive to happiness, conformity to the course of conduct required by it, must be the highest happiness. Conformity to the course of conduct pointed out by the moral faculty as conducive in the highest degree to happiness, is moral excellence, or, in the definite and exact sense of the word, virtue. And in this sense it is that virtue is happiness. It is because it discriminates the true sources of happiness, that is, directs every other faculty into its proper course, and guides it in that course to the attainment of its ultimate object, that the moral faculty takes the high place it does among the faculties of the human mind. Supposing the operation of this faculty to be perfect, it is but an identical expression to say, that to follow its guidance implicitly is to follow the road that leads to the most perfect happiness.

But there is another faculty which is as truly a part of the human mind as the moral faculty, and to the possession of which there is nothing in the slightest degree analogous in any other creature known to us. It is impossible for the human mind not to infer the existence of a Creator from the study of the creation. It is impossible to contemplate the attributes of the Creator, such attributes at least as those ascribed to Him by the Christian Revelation, without reverence, trust, and love. But the ascription of such attributes to the Creator, the feeling of reverence, trust, and love towards Him, and the desire and endeavour to conform in heart and life to His law, as far as His will is known, is religion. And the exercise of the religious faculty, under the true and enlightened guidance of the Christian Revelation, is at once man's greatest privilege, and includes the highest happiness of which his nature is susceptible.

Thus manifest it is, from every view that can be taken of the constitution of human nature, that every faculty with which it is endowed, from the lowest to the highest, not only affords its own proper and peculiar pleasure, but that each, as it successively rises in the scale, is proportionately the source of a nobler kind, and a larger amount of enjoyment.

And the pleasure thus afforded by the various faculties with which the human being is endowed is the immediate and direct result of their exercise. With the exception of the organic organs, and the reason for the exception in regard to them has been assigned, the action of the organs is directly pleasurable. From the exercise of the organs of sense, from the operation of the intellectual faculties, from appetite, passion, and affection, pleasure flows as directly as the object for which the instrument is expressly framed.

And pleasure is the ordinary result of the action of the organs; pain is sometimes the result, but it is the extraordinary, not the ordinary result. Whatever may be the degree of pain occasionally produced, or however protracted its duration, yet it is never the natural, that is, the usual or permanent state, either of a single organ, or of an apparatus, or of the system. The usual, the permanent, the natural condition of each organ, and of the entire system, is pleasurable. Abstracting, therefore, from the aggregate amount of pleasure, the aggregate amount of pain, the balance in favour of pleasure is immense. This is true of the ordinary experience of ordinary men, even taking their physical and mental states such as they are at present; but the ordinary physical and mental states, considered as sources of pleasure of every human being, might be prodigiously improved; and some attempt will be made, in a subsequent part of this work, to show in what manner and to what extent.

It has been already stated that there are cases in which pleasure is manifestly given for its own sake; in which it is rested in as an ultimate object: but the converse is never found: in no case is the excitement of pain gratuitous. Among all the examples of secretion, there is no instance of a fluid, the object of which is to irritate and inflame: among all the actions of the economy, there is none, the object of which is the production of pain.

Moreover, as already stated, all such action of the organs, as is productive of pleasure, is conducive to their complete development, and consequently to the increase of their capacity for producing pleasure; while all such action of the organs as is productive of pain is preventive of their complete development, and consequently diminishes their capacity for producing pain. The natural tendency of pleasure is to its own augmentation and perpetuity. Pain, on the contrary, is self-destructive.

Special provision is made in the economy for preventing pain from passing beyond a certain limit, and from enduring beyond a certain time. Pain, when it reaches a certain intensity, deadens the sensibility of the sentient nerve; and when it lasts beyond a certain time, it excites new actions in the organ affected, by which the organ is either restored to a sound state, or so changed in structure that its function is wholly abolished. But change of structure and abolition of function, if extensive and permanent, are incompatible with the continuance of life. If, then, the actions of the economy, excited by pain, fail to put an end to suffering, by restoring the diseased organ to a healthy state, they succeed in putting an end to it by terminating life. Pain, therefore, cannot be so severe and lasting as materially to preponderate over pleasure, without soon proving destructive to life.

But the very reverse is the case with pleasure. All such action of the organs as is productive of pleasure is conducive to the perpetuation of life. There is a close connexion between happiness and longevity. Enjoyment is not only the end of life, but it is the only condition of life which is compatible with a protracted term of existence. As a rule, the happier a human being is, the longer he lives; the more he suffers, the sooner he dies; to add to enjoyment, is to lengthen life; to inflict pain, is to shorten the duration of existence. As there is a point of wretchedness beyond which life is not desirable, so there is a point beyond which it is not maintainable. The man who has reached an advanced age cannot have been, upon the whole, an unhappy being; for the infirmity and suffering which embitter life cut it short. Every document by which the rate of mortality among large numbers of human beings can be correctly ascertained contains in it irresistible evidence of this truth. In every country the average duration of life, whether for the whole people or for particular classes, is invariably in the direct ratio of their means of felicity; while, on the other hand, the number of years which large portions of the population survive beyond the adult age may be taken as a certain test of the happiness of the community. How clear must have been the perception of this in the mind of the Jewish legislator when he made the promise, THAT THY DAYS MAY BE LONG IN THE LAND WHICH THE LORD THY GOD HATH GIVEN THEE—the sanction of every religious observance, and the motive to every moral duty!

Deeply, then, are laid the fountains of happiness in the constitution of human nature. They spring from the depths of man's physical organisation; and from the wider range of his mental constitution they flow in streams magnificent and glorious. It is conceivable that from the first to the last moment of his existence, every human being might drink of them to the full extent of his capacity. Why does he not? The answer will be found in that to the following question. What must happen before this be possible? The attainment of clear and just conceptions on subjects, in relation to which the knowledge hitherto acquired by the most enlightened men is imperfect. Physical nature, every department of it, at least, which is capable of influencing human existence and human sensation; human nature, both the physical and the mental part of it; institutions so adapted to that nature as to be capable of securing to every individual, and to the whole community, the maximum of happiness with the minimum of suffering—this must be known. But knowledge of this kind is of slow growth. To expect the possession of it on the part of any man in such a stage of civilization as the present, is to suppose a phenomenon to which there is nothing analogous in the history of the human mind. The human mind is equally incapable of making a violent discovery in any department of knowledge, and of taking a violent bound in any path of improvement. What we call discoveries and improvements are clear, decided, but for the most part gentle, steps in advancement of the actual and immediately-preceding state of knowledge. The human mind unravels the great chain of knowledge, link by link; when it is no longer able to trace the connecting link, it is at a stand: the discoverer, in common with his contemporaries, seeing the last ascertained link, and from that led on by analogies which are not perceived by, or which do not impress others, at length descries the next in succession; this brings into view new analogies, and so prepares the way for the discernment of another link; this again elicits other analogies which lead to the detection of other links, and so the chain is lengthened. And no link, once made out, is lost.

Chemists tell us that the adjustment of the component elements of water is such, that although they readily admit of separation and are subservient to their most important uses in the economy of nature by this very facility of decomposition, yet that their tendency to recombination is equal, so that the quantity of water actually existing at this present moment in the globe is just the same as on the first day of the creation, neither the operations of nature, nor the purposes to which it has been applied by man, having used up, in the sense of destroying, a single particle of it. Alike indestructible are the separate truths that make up the great mass of human knowledge. In their ready divisibility and their manifold applications, some of them may sometimes seem to be lost; but if they disappear, it is only to enter into new combinations, many of which themselves become new truths, and so ultimately extend the boundaries of knowledge. Whatever may have been the case in time past, when the loss of an important truth, satisfactorily and practically established, may be supposed possible, such an event is inconceivable now when the art of printing at once multiplies a thousand records of it, and, with astonishing rapidity, makes it part and parcel of hundreds of thousands of minds. A thought more full of encouragement to those who labour for the improvement of their fellow-beings there cannot be. No onward step is lost; no onward step is final; every such step facilitates and secures another. The savage state, that state in which gross selfishness seeks its object simply and directly by violence, is past. The semi-savage or barbarous state, in which the grossness of the selfishness is somewhat abated, and the violence by which it seeks its object in some degree mitigated, by the higher faculties and the gentler affections of our nature, but in which war still predominates, is also past. To this has succeeded the state in which we are at present, the so-called civilized state—a state in which the selfish principle still predominates, in which the justifiableness of seeking the accomplishment of selfish purposes by means of violence, that of war among the rest, is still recognized, but in which violence is not the ordinary instrument employed by selfishness, its ends being commonly accomplished by the more silent, steady, and permanent operation of institutions. This state, like the preceding, will pass away. How soon, in what precise mode, by what immediate agency, none can tell. But we are already in possession of the principle which will destroy the present and introduce a better social condition, namely, the principle at the basis of the social union, THE MAXIMUM OF THE AGGREGATE OF HAPPINESS; THE MAXIMUM OF THE AGGREGATE OF HAPPINESS SOUGHT BY THE PROMOTION OF THE MAXIMUM OF INDIVIDUAL HAPPINESS!

CHAPTER IV.

Compound nature of natural bodies—Inorganic and organic elements—Essential and incidental organic elements—Organic constituents—Peculiarity and complexity of combination proper to organic elements—Proximate principles: vegetable and animal—Non-nitrogenised and nitrogenised—Albumen, fibrin, casein, protein—Isomeric substances.

MATTER, as far as is known to man, is either solid, liquid, or gaseous. In one or other of these forms it makes up the earth, the sea, the air, and all they contain. But few substances as they exist in nature consist of one kind of matter only. They are nearly all composed of different materials, variously aggregated together, and more or less intimately combined; and the object of science is to separate these compounds into their component parts, to ascertain the properties peculiar to each constituent, and to discover the laws which govern their combination and mutual action.

Modern chemistry has accomplished these objects with a high degree of success. It has subjected almost every accessible substance to experiment, and the general result of its analyses is to show, what has just been stated, that nearly all natural bodies, however simple they may appear, are really made up of more than one substance.

A mass of marble, for example, judging from its external appearance, would hardly be supposed to consist of more than one description of matter. It is really composed of three. By the application of heat, a piece of marble is first of all broken up into two substances, one a solid, quick lime; and the other a gas, carbonic acid gas. On further analysing the quick lime, that also is found to be composed of two bodies, namely, a metal, calcium, and a gas, oxygen; while the carbonic acid, in its turn, consists of two bodies, carbon and oxygen.

Marble is thus proved to be a compound of calcium, carbon, and oxygen. But on subjecting the latter bodies to experiment it is found that the analysis can go no further; they cannot be resolved into any simpler form of matter; they are therefore called elements, and they must be so regarded until future discoveries show that some other substance not yet known enters into their composition.

About sixty-two of such bodies have been obtained, of which a list is given in Appendix No. I; but the catalogue is continually changing; one substance being removed from the list, and another added to it, as experiment proves it to be compound or simple.

Of these Inorganic Elements four only form the basis of organic bodies, namely, carbon, oxygen, hydrogen and nitrogen; and their relative abundance is nearly in the order of this enumeration. They are called essential organic elements, but to these are added minute quantities of other simple substances, as sulphur, phosphorus, chlorine, fluorine, potassium, sodium, calcium, magnesium, iron, silicon, manganese, aluminum and copper. These are named *Incidental Organic Elements;* but this term must not be understood in the sense of accidental; nor be allowed to convey the impression that they are of no determinate and essential use. They answer purposes of the utmost importance, as will be seen immediately.

Out of the whole number of inorganic bodies, then, only seventeen have as yet been discovered in the organic kingdom.

The essential organic elements never enter into the composition of organic bodies as elements. They first unite with each other in definite proportions, and form compounds of a determinate nature. Thus oxygen unites with carbon in the proportions that form carbonic acid; hydrogen with oxygen in the proportions that form water; nitrogen with hydrogen in the proportions that form ammonia; and it is only as carbonic acid, water and ammonia, that the elements—now indeed no longer elements, but compound bodies—enter the organic world. The compounds thus formed are commonly named *Organic Constituents.*

Organic constituents thus combined with one or more incidental elements, unite together in definite proportions and form distinct organic substances, commonly termed *Proximate Principles*—principles to distinguish them from elements, and proximate because they are the products of the first combinations of the organic constituents. The compounds thus formed may be said to stand on the verge of the organic world, but not to have entered it: they are not organised substances, but organisable: not living, but capable of being endowed with life: they have acquired new and peculiar properties and powers, such as are never manifested by inorganic bodies, and in order to distinguish them from the latter they are called "Vital;" yet they must not be regarded as formed by a peculiar vital principle different from ordinary chemical affinity, but as products of common chemical affinity, operating under conditions which present themselves only in living bodies.

Since four elements make up the main bulk of the countless varieties of organic matter, they must be endowed with extraordinary powers of combination, and, indeed, there appears to be no limit to the number of definite substances they are capable of generating, each marked by a perfect individuality of its own.

These elements in combining are further distinguished by the peculiar mode of their association, which is altogether different from that of inorganic bodies. They are characterized by what may be termed a binary plan of combination: union takes place between pairs of elements; the compounds so produced again unite themselves to other bodies in the same manner, so that the most complicated organic compounds are constructed by this repeated pairing on the part of their constituents. No such arrangement can be traced in inorganic bodies, the elements of which are bound up together into a single whole, which can enter into combination with other substances, and be thence disengaged with properties unaltered.

The power of thus forming complex combinations is greatly aided by the action of the Incidental Elements, which exert an all-important influence over the chemical unions and disunions of organic substances. It is conceived that these elements are endowed with a power of repulsion, and that, being universally diffused through organic matter, they retain it by virtue of this power in a state of fluidity, or of solubility, and in the same way they prevent it from assuming a crystalline structure. Thus in the familiar process of cheese-making, the curd which contains the casein, or cheesy matter, is separated from the whey, in consequence of the formation of a little acid derived from the milk sugar in the whey, just sufficient in quantity to neutralise the alkaline matter which holds the casein in solution, and the alkali being thus withdrawn, the casein is no longer capable of maintaining its fluid state, and is precipitated as a solid substance. Mr. Rainey has also shown that the presence of phosphate of lime is necessary to prevent the carbonate from assuming a crystalline form.

Proximate principles are either vegetable or animal, the distinctive characters of which may be thus briefly stated:—

VEGETABLE PROXIMATE PRINCIPLES.—These consist for the most part of three only of the essential elements, namely, carbon, oxygen, and hydrogen; they are therefore ternary compounds, composed generally of carbon combined with the elements of water. Not that the fourth element, nitrogen, is absent from the vegetable kingdom. It exists in every plant, and is absolutely essential to its health and vigour, and to the performance of some of its most important functions; but still as a constituent it forms but a small part of vegetable substance.

ANIMAL PROXIMATE PRINCIPLES.—These are generally composed of all the four essential elements. They are therefore quaternary compounds, and thus exhibit a high complexity of composition in their very elemental forms.

The remarkable fact that some Proximate Principles, both vegetable and animal, are destitute of nitrogen, affords a well-defined character by which they may be divided into two groups, the non-nitrogenised, and the nitrogenised.

Non-Nitrogenised Proximate Principles.—Among the chief of these are the familiar substances sugar, starch, gum, cellulose, lignin, &c.

Sugar, composed of $\text{Carbon}_{24}\text{Hydrogen}_{22}\text{Oxygen}_{22}$, is found in the juices of plants, in the sap of trees, and in many roots, particularly in fleshy roots, as the beet. Cane sugar forms large, transparent, colourless crystals; it is very soluble in water; it is capable of undergoing fermentation; it is nearly always in a state of solution in plants, and is especially abundant in growing parts, such as buds and germinating seeds; it is an organic substance, but close on the confines of the inorganic kingdom, as is indicated by its tendency to crystallization; it performs highly important uses in the vegetable economy, and is an essential ingredient in the processes of nutrition and maturition.

Starch, $C_{24}H_{20}O_{20}$, is perhaps the most important and widely diffused of all the Vegetable Proximate Principles. It exists in every plant, but it is most abundant in the roots and tubers of certain plants, as in the potato, and in general in soft stems and in seeds. It is insoluble in cold, but soluble in boiling water; to the naked eye it presents the appearance of a soft, white, glistening powder; under the microscope it is seen to be destitute of crystalline structure, and to be made up of little, rounded, transparent bodies, upon each of which a series of depressed, parallel rings, surrounding a central spot, or *hilum*, may often be traced. This principle is of somewhat higher organic character than sugar, since it is no longer capable of the crystalline structure; it even indicates some traces of organisation; it is the chief material of vegetable nutrition, and for this purpose it is stored up in cotyledons, buds, tubers, &c., to be ready when required.

Gum, $C_{24}H_{22}O_{22}$, forms white or slightly yellowish irregular masses, destitute of crystalline structure. It is soluble in cold water, forming a viscid, adhesive, tasteless solution, called mucilage. It is nutritive, and forms a nidus for the reception and development of the simplest vegetable organisms, to the structure of which it contributes the chief material.

Cellulose, $C_{24}H_{20}O_{20}$. This substance, which forms the external walls of cells, and constitutes cellular membrane in general, is tough, elastic, colourless, transparent, and insoluble in any known menstrua. It is readily permeable by fluids. It is closely allied in composition to starch, and is convertible into it.

Lignin $C_{24}H_{20}O_{20}$. Identical in composition with starch, it is insoluble and innutritious, and constitutes the basis of the solid structures of all plants. Fine linen and cotton are examples of it in a pure state, the associated vegetable principles having been removed or destroyed by the variety of treatment to which the fibre has been subjected. It is convertible into another proximate principle, Dextrine, which in its turn may be converted into grape sugar. Linen rags may be made to furnish more than their own weight of this description of sugar.

Nitrogenised Proximate Principles.—The nitrogenised proximate principles, both in plants and animals, are comprehended in three groups, which have received the names of fibrin, albumen, and casein.

Vegetable Fibrin.—Contained chiefly in the juices of plants. When freshly expressed vegetable juices are allowed to stand at rest a deposit is thrown down, consisting of a solid substance of a green colour, which, when the colouring matter is removed, becomes greyish white. This deposit is vegetable fibrin.

Vegetable Albumen.—When the juice has deposited its fibrin, it still retains in solution a substance which does not separate at the ordinary temperature of the atmosphere, but coagulates when the juice is heated to the boiling point. This coagulum is vegetable albumen.

Vegetable Casein.—The flower seeds of certain plants, particularly those of the leguminous order, such as peas, beans, and lentils, yield a coagulum wholly different from that afforded by the expressed juices, and similar to the curdy or cheesy ingredient of animal milk. This is vegetable casein.

Animal Fibrin.—It will be seen hereafter that when the vein of a living animal is opened, and the blood is allowed to stand at rest for a few minutes, the fluid separates into two parts—a pale-yellowish liquid, called serum, and a solid portion, named the clot. The clot in its turn separates spontaneously into two parts, one of which consists of the red particles of the blood, and the other of a solid, tasteless, insoluble substance, which is animal fibrin, and which has a peculiar tendency to arrange itself into long white, elastic, parallel threads, or fibres, whence its name.

Animal Albumen.—Just as in the case of vegetable albumen, when heat is applied to the liquid part of the blood, the serum, it coagulates and throws down a white solid substance identical with white of egg. This is animal albumen.

Casein.—A white curdy substance, the nitrogenised component of milk. It is not sensibly soluble in pure water, but readily dissolves in water containing a very small quantity of alkali. Its most striking property is its coagulability by certain animal membranes, as that of the stomach of the calf.

When albumen, fibrin, and casein are subjected to a chemical process which removes from them all foreign substances, a snow-white flocculent matter is obtained, which is free from sulphur and phosphorus. This substance is regarded as the common basis of the three albuminous principles, which are conceived to be merely modifications of this peculiar matter with different proportions of sulphur and phosphorus. It has accordingly received the name of Protein, (from πρωτεῖος, "first in place,") in allusion to its alleged relation to the albuminous principles.

On referring to the preceding chemical analysis it will be seen that the base of the vegetable proximate principles, Carbon, remains invariably the same through the entire series, while the differences in the proportions of their hydrogen and oxygen range only from one to three. Thus, take away from sugar three portions out of twenty of hydrogen, and two of oxygen, the result is starch. Add to starch two of oxygen and two of hydrogen, and the product is gum. To ten parts of vegetable protein add one of phosphorus and one of sulphur, and the result is vegetable fibrin: add to the same parts of protein one of phosphorus and two of sulphur, and the result is vegetable albumen: abstract the phosphorus altogether, and add one part of sulphur, and the result is vegetable casein. So to animal albumen add two or three portions more of carbon and less of oxygen, the other constituents remaining in nearly the same proportions, and the result is animal fibrin.

So close indeed is the relation between all these principles that when two analyses are made, one of fibrin and one of albumen, the results do not differ more than in two analyses of fibrin and two of albumen respectively. But it sometimes happens that all the elements unite in identically the same proportions, and yet the products differ widely from each other in their external characters and properties. Bodies of this kind form a distinct class peculiar to the organic kingdom. They are called Isomeric. Sugar is isomeric with gum, lignin with cellulose, and the albuminous principles with each other. The explanation of these remarkable phenomena appears to be that in all bodies of this kind, though the elements are the same, they have, as has been stated, a peculiar arrangement in each individual substance, which gives to each a peculiar constitution, and therefore special properties.

So complete are the analyses which have led to the discovery of the facts now stated, that there is scarcely anything to be desired with respect to the knowledge attained of the ultimate composition of organic matter. Yet chemistry, which has so admirably displayed its analysis, has wholly failed to accomplish its synthesis. The chemist can analyse organic matter, but he cannot make it; not even a particle of sugar, the substance which stands on the very confines of the inorganic world. The plant can make it, and so can the insect, but not the chemist. Some few of the binary inorganic compounds he has separated into their elements, and then, by again combining them, he has reproduced the substance he had decomposed. He has resolved water, for example, into its elements, and then, re-uniting them by the electric spark, he has exhibited within his own little apparatus the creation of water as perfect as that which falls from the cloud or condenses in dew.* But he cannot so re-combine the elements of sugar or gum, of albumen or fibrin; yet he knows the exact proportions in which the elements unite to produce these substances, and he witnesses their actual transformation in every leaf that grows and every flower that blooms; but the subtle process by which the change is effected he knows not, and cannot imitate.

He cannot do this because he cannot command, and does not even know, the conditions on which the formation of these substances depend. The chemistry by which they are generated is doubtless the same in its essential nature as that by which the crystal is produced, but organic substances, as already stated, can be formed only under conditions peculiar to life, and these conditions appear to be placed beyond human control and forbidden to human knowledge.

The facts which have been stated place in a striking point of view the unity of the organic world—created out of the same elements, few in number, but illimitable in the variety of their combinations; the resulting substances acquiring new and peculiar forces, and being obedient to new and peculiar laws, the forces and laws of life.

They further prove the highly interesting and suggestive fact that organic matter is a manufactured material; that it undergoes special processes to fit it for special uses. Just as cotton, wool, and silk are brought by preparatory processes into a condition fit to be woven into the varied fabrics of the factory, so albumen, fibrin, and casein, by the vital processes they undergo, are elaborated and modified until they become fit to build up the exquisite fabrics of the living body.

And the actual processes through which they pass, particularly in the early stages of their formation, are so surprising that, if the scientific researches which have discovered the facts had not established them by indubitable evidence, they would surpass belief. They could not be known before the microscope had acquired a certain magnifying power and distinctness of definition. To all antiquity, therefore, this part of nature was a sealed book. It is only within the present century, chiefly within the last quarter of it, that a bright beam of light has been thrown on this most interesting part of the Creator's works: it is by the concurrent and coinciding observation of the greatest physiologists of Germany, France and England, that the curious and extraordinary phenomena immediately to be described have been established, and it is by their united hands that the veil has been removed which shrouded in total darkness the wonders of this, till now, invisible world.

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* Dr. Hope, of the University of Edinburgh, in repeating annually before his class the original experiment of Cavendish, by whom this combination was first effected, was accustomed to preserve for a series of years the water formed in his apparatus during the hour of lecture. Few objects of art or science have excited greater wonder and reverence than that little decanter of water.

CHAPTER V.

Of Cells.

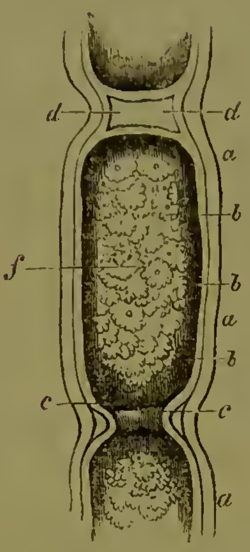
WITHIN the period last referred to, a remarkable work appeared in Germany by a physiologist of the name of Schleiden, who published the result of an extended series of microscopical examinations into the elementary form and structure of vegetable tissues and organs. This was soon followed by his countryman Schwann, who made the like laborious investigation of the elementary structures of animal organisms. These works laid the foundation of a new branch of physiological science, under the name of Histology, from ἱστὸς, a web, and λογος, a discourse; the science which treats of organic forms and structures too minute to be visible to the naked eye. The subject has been subsequently investigated by the most distinguished physiologists both of our own country and abroad, and the general result must appear to every one who hears it for the first time the most surprising within the range of science, namely, that every plant and animal begins existence at the same starting point, by a particle of organic matter essentially the same in nature, and always the same in form; a microscopic cell, so similar throughout the organic kingdom, that the most skilful microscopists are unable to discover any characters by which this elementary body can be distinguished in the highest animal, and in the lowest plant.

An organic cell consists of a film of organic matter, moulded into the form of a vesicle or bladder, sometimes called a utricle, from *utriculus*, the diminutive of *uter*, a bottle. This film which forms the cell-wall is transparent, structureless, and so thin that it cannot be measured, yet it possesses some degree of firmness, for it holds within it the elementary matter from which all organized beings take their origin.

In vegetable cells, immediately within the cell-wall, there is a thin, delicate lining of organic matter, which is easily detached from the proper membrane of the cell by water, acids, and tincture of iodine;

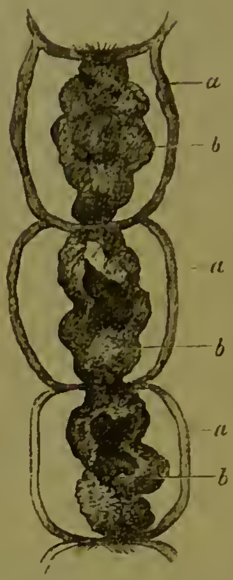
the latter colouring it brown, and causing it to contract. (Fig. 2, *b*.)

Fig. 1.



Elongated cells:—*a*, cell membrane; *b*, primordial utricle; *c*, ditto, folding inwards, and beginning to form a septum; *d*, septum fully formed; *f*, cell contents, after Hantrey.

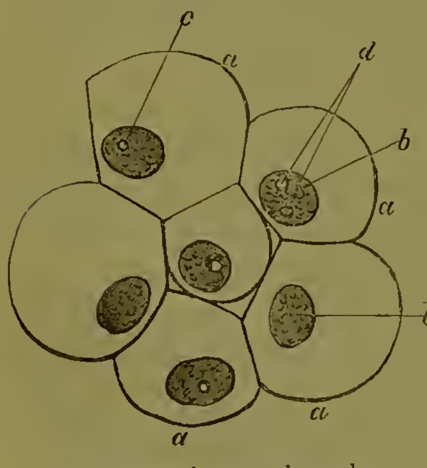
Fig. 2.



a, cell membrane; *b*, primordial utricles detached from the cell membrane by tincture of iodine, thickened, enclosing the nuclei, and continuous through the yet incomplete septa.

This is termed, from the physiologist who first described it, the Primordial utricle of Mohl. As it is spread uniformly over the whole internal surface of the cell-wall (Fig. 1, *b*), it must of course enclose all the other contents of the cell.

Fig. 3.



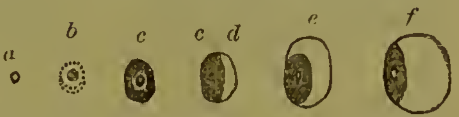
a, cell membrane; *b*, nucleus; *c*, nucleolus; *d*, nucleoli.

Those other contents are, first, a quantity of pellucid semifluid organic matter, and secondly, two minute more solid bodies embedded in this fluid, the largest of which is called the nucleus (Fig. 3, *b*), and the smallest, contained within the first, the nucleolus (Fig. 3, *c*). These bodies give name to the cells, which are called nucleated cells.

The fluid in which these bodies are embedded is a nitrogenous substance, a protein compound, in plants of a mucilaginous, in animals of an albuminous character; in both holding in suspension a considerable proportion of oils, a fatty matter combined with earthy and saline salts, and some animal ingredient. Its chemical composition is essentially the same in all classes of organized beings. As it is conceived to be the material from which cells derive their origin and support, it is called "germ substance," or blastema, from βλαστημα, a bud or blossom; and being further supposed to take a direct share in the formation of the elementary parts, it is also called *formative fluid*, or cytoblastema, from κυτος, a vesicle, and βλαστημα, germ substance.

When a cell is about to be formed, a certain movement takes place in the blastema; some of its particles become aggregated together, or a deposit is thrown down. A minute solid granule is the result, the nucleolus; then the particles aggregate into a still larger body, and form the nucleus. As soon as formed, the nuclei begin actively to attract new particles, which are deposited upon and around them, condensing into the film or membrane, and constituting the cell-wall. (Fig. 4.) At first the membrane is in close contact with the nucleus, so that the nascent cell is but little larger than the nucleus (Fig. 4, *d.*); but as the membrane admits more and more blastema through its porous walls, it gradually becomes distended, rises up like a watch-glass above the face of a watch, completely encloses the nuclei with their surrounding liquid, and thus is completed the perfect cell. (Fig. 4, *e*, *f.*)

Fig. 4.



a, nucleolus; *b*, nucleus; *c*, *c*, nucleus in close contact with cell membrane; *d*, *e*, *f*, membrane rising progressively more and more above nucleus.

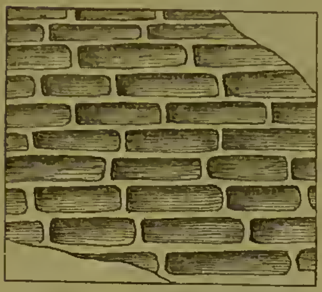
The elementary parts of the cell unquestionably become modified in their composition, and acquire new properties from their particular structure; for when an entire cell is exposed to certain chemical agents its several parts are differently acted upon, acetic acid dissolving its liquid contents, while it leaves the nucleus entire, and even renders it more sharply defined and more conspicuous, and sometimes completely dissolving the membrane and so setting the nucleus free. The same is true of the nucleolus.

With regard to the function of these bodies, Schleiden regarded the nucleolus as the "prime factor" in the formation of new cells, and accordingly called it the cytoblast or cell-germ, terms already explained. Others extend his views, and regard the nuclei, together, as the active agents in producing the chemical or organic changes that take place in the fluid contents of cells, and in modifying and elaborating the various products they form.

The primary nucleated cell, when not subject to pressure, is a perfect circle or sphere, a form calculated to hold the largest amount of matter in the smallest space; but cells assume all sorts of figures according to the degree and nature of the pressure to which they are exposed. Figs. 5, 6, 7 show their altered forms from pressure.

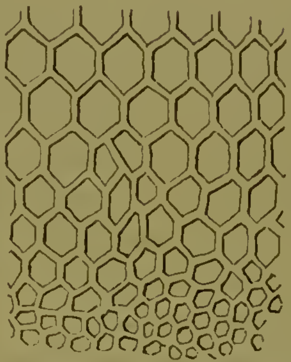
They also vary greatly in size, according to the tissue or organ in which they are examined, varying from the $\frac{1}{1500}$th to the $\frac{1}{2000}$th part of an inch in diameter. Their membranous wall renders them perfectly closed sacs, though fluids readily pass through them by a process hereafter to be described.

Fig. 5.



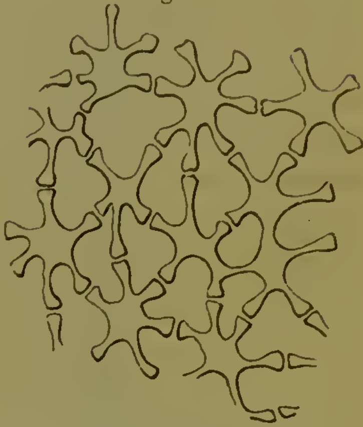
Muriform cells altered by pressure.

Fig. 6.



Cluster of cells showing their altered form from equal pressure, producing regular hexagons.

Fig. 7.



Cells altered by pressure.

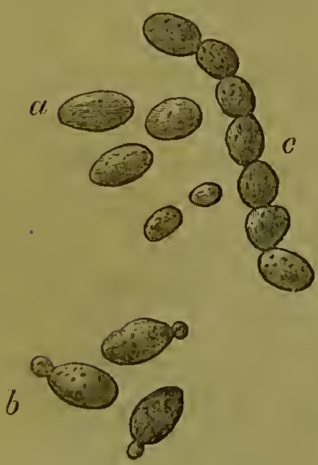
Cells acquire and exercise the following functions:—

1. The function of absorption: they draw into their interior through their permeable walls portions of the formative fluid by which they are surrounded (blastema).

2. The function of secretion: they act variously on this common matter so as to form out of it products widely different from each other.

3. The function of assimilation: they appropriate part of the matter they absorb to their own nourishment and growth.

Fig. 8.



a, single cells of yeast plant; *b*, cells beginning to sprout; *c*, a row of full-grown cells adhering together, and forming a necklace appearance.

4. The function of reproduction: they increase in number as well as size, an object which they accomplish in one or other of the following ways:

At one or two points of the external surface of a full-grown cell, minute projections or sprouts make their appearance (Fig. 8, *b*). These prove to be young cells, which rapidly develop into perfect cells. This is well seen in the yeast plant, when placed in contact with a solution of sugar or infusion of malt, and observed under the microscope. The simple ovoid cell soon begins to sprout (Fig. 8, *b*); each sprout develops into a young cell, and these, when full grown, give to the plant the appearance of a necklace (Fig. 8, *c*).

A contraction takes place in a full-grown cell (Fig. 1, *c*), by the gradual enfolding of the primordial utricle; the fold growing inward to the centre, until the division becomes complete (Fig. 1, *d*); and the parent cell then spontaneously separates into two or four cells; a mode of multiplication called fissiparous cell-formation.

Cells are capable of developing with incredible rapidity. Thus in the mushroom tribe, Bovista giganteum, a species of fungus, has been known to grow in a single night from the size of a mere point to that of a large gourd. Taking the estimate of Professor Lindley, that the cells of this plant are $\frac{1}{1200}$ of an inch in diameter, a plant of the size of the Bovista will contain no less than 47,000,000,000 cells, which it develops at the rate of nearly 4,000,000,000 per hour, or of more than 66,000,000 per minute. Large tracts of land are often covered in a single night with vegetable growths, consisting of clusters of cells, many millions of which are contained in the space of an inch.

Among the changes which cells undergo, the most interesting are those which fit them for becoming constituent parts of tissues and organs.

CHAPTER VI.

Of the connecting and supporting tissues—Areolar tissue, tendon, membrane, cartilage, bone, ivory.

Much progress has been made of late years in the knowledge of the minute structure of organs and tissues, so that their history has become a new science, and has received the name of Histology. To treat fully upon this science at the present day would require the space of a large volume, for the number of its facts which have been found out and gathered together is very great.

The bodies of all living creatures are at some time in their history composed altogether of cells, and some lowly organisms both in the animal and vegetable kingdom never develop into any structure more elaborate than a group of these. But in the higher forms, especially of animals, this condition is only temporary, and the cells which at first compose the incipient frame of the future being quickly pass through such courses of change as shall produce the kind of structure proper to the organ which is to arise and develop in the position which they occupy.

Now in many—nay most—parts, the changes of the primary cells which conduct to the perfect organ are thoroughly consummated, and the original cellular condition is effaced, so that one who is not familiar with the history of development could never find, in the completed tissue, anything to suggest to him that it was cellular in the beginning. Yet the last traces of the primitive form are rarely, we may say never, totally obliterated. A sufficiently attentive inspection with a powerful microscope will show, in all the tissues, the nucleus of the original cells remaining. The nucleus, which in the early cell seemed to be the centre wherefrom the vital processes were governed, and wherein the power of self-nurture had its site, appears in all the succeeding history, however much the cell may change, to exercise some of its old influences; to radiate to its close vicinity the creative power which it displayed when the cells were originally transformed, in producing from indifferent material the substance of muscle, or aught else, according to its kind.

The tissues which arise by this development from cells are very various in their character; each kind is endowed with physical and vital powers suitable to its use in the body. In some of the substances of which the body is composed the cellular form is permanent, being retained at all periods of life; such are cartilage, clothing and lining cuticle, blood, and some others. In the class of connective and supporting tissues, which includes bone, tendon, and membrane, part of the cells remain in a modified shape, whilst others are transformed into fibres. In yet a third group of structures, as muscular and nervous fibre, the nuclei of the original cells alone remain in the fully-developed tissue.

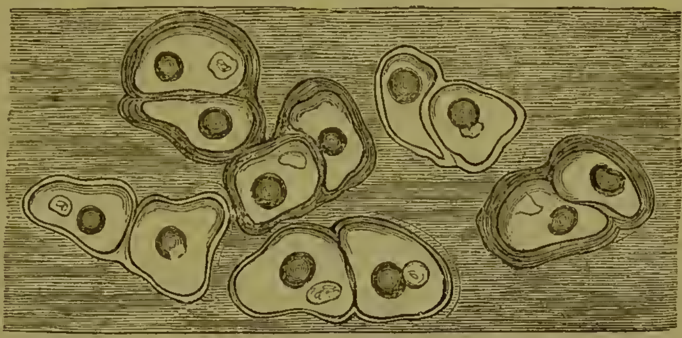
These elementary tissues enter into different combinations with each other to constitute the organs of the body; each tissue brings its proper characters and powers, its rate of vital change, and liabilities to disorder and decay. Many of them are very generally distributed through the body, and the entire quantity of any tissue, when regarded as a whole, is called a system; thus all the nervous tissue in the body taken together is called the nervous system, all the muscles the muscular system, all the vessels the vascular system, and so forth.

Everywhere in the body the component parts of any system present the same structure, but there are some organs, as for instance the eye and ear, which contain tissues peculiar to themselves. These special tissues are however very small in amount, compared with the quantity in which any of the tissues composing systems are present.

Some of the systems offer mutual resemblances both in structure and properties, so as to prove their affinity to each other: such a relation exists in that group of systems to whose part falls the performance of the more strictly mechanical offices in the body. The osseous system for support; the ligamentous system for connecting the bones; the cartilages which supply elasticity in such situations as they occupy; the tendons and membranes which guide the muscular power to the bones; and lastly, the areolar tissue, a soft and supple web, which connects the adjacent surfaces of organs. Throughout these systems, though they differ much in their outward appearance at first sight, there runs a gradation in complexity of structure from cartilage, which is cellular, up to bone, which presents to us an elaborate arrangement of calcified membrane, blood canals, and modified cells.

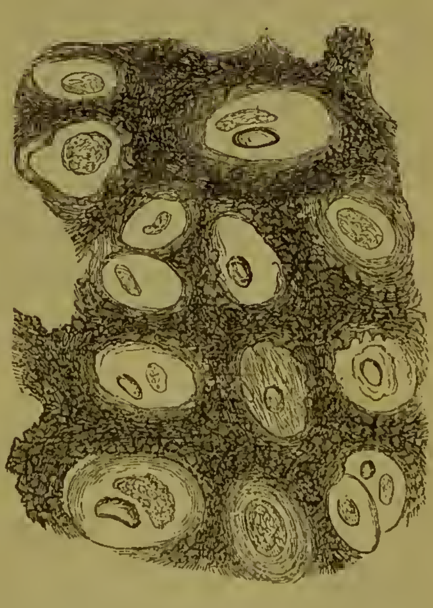
True cartilage, such as is found on the ends of bone, and between the ribs and sternum, and such as foreshows and moulds the shape of the future bone in the earliest periods of life before the production of bone begins, consists of cells embedded in a clear translucent homogeneous material (Fig. 9). The cells are generally gathered into little groups, and contain a nucleus and nucleolus within them; they are separable from the little cavities in which they are lodged. Thus cartilage proper much resembles the cellular tissue of plants (Fig. 1), the cells in both cases being surrounded by a substance differing from themselves, and from which their own proper enclosing wall is separable. In some cartilages the intercellular material shows evidence of a separation into fibres (Fig. 10). The evidence varies in degree in different cases; in some there is an exceedingly slight trace, such that we can just see delicate lines throughout it; in others, the fibrous condition so prevails that the section presents us with filaments, interlacing into a close matted web, with meshes throughout it in which the cells are lodged: this kind of cartilaginous material, where the fibrous state predominates, is called "fibro-cartilage;" it is employed in the formation of the nose, ears, air tube, etc., to give definite shape to the part, whilst a great degree of pliancy is allowed. From this structure we easily pass to tendons and membrane. In these the minute fibres, instead of being felted together as in fibro-cartilage, are arranged

Fig. 9.



Human cartilage-cells, from the whitish layer of the cricoid cartilage; magnified 350 times.

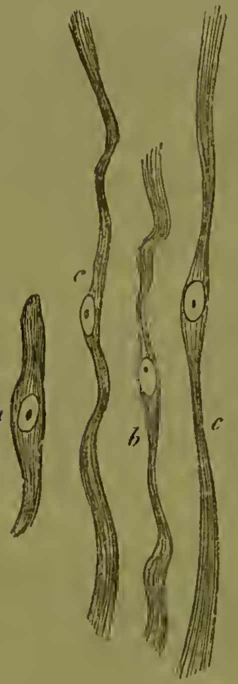
Fig. 10.



A piece of the human epiglottis; magnified 350 times.

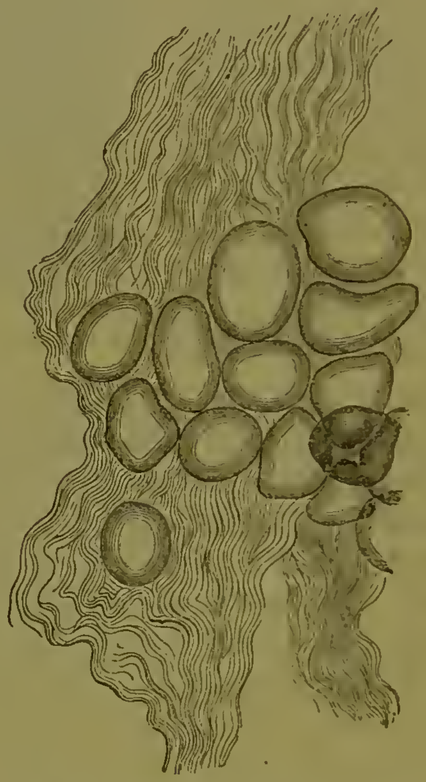
parallel to each other in strong bundles, and these are gathered together into the cords of tendon, or woven into sheets of membrane. In either situation the fibres run principally in the direction where the strain is greatest, and are connected together by other weaker fibres which run across them. The character of the component fibres is the same as in the areolar tissue, to be presently noticed. They are fine sinuous filaments arranged parallel in little bundles, and are produced from the original cells, most of which, in the progress of development, elongate and divide up into fine fibres (Fig. 11), whilst some remain in the form of star-shaped communicating cells, as is also the case with areolar tissue.

Fig. 11.



Formative cells of areolar tissue, from the skin of the trunk of a sheep's embryo, seven lines long; magnified 350 times. *a*, cell without any indication of fibrils; *b*, with commencing, and *c*, with distinct fibrils.

Fig. 12.



Loose areolar tissue, with fat cells; of man. Magnified 350 times.

The membranes above alluded to—fasciæ as they are called—are found of all degrees of thickness and strength, from such dense sheets of fibrous tissue as enclose the muscles of the thigh to the most slender films, which pass without limit into true *areolar tissue* (Fig. 12), a substance which, whilst it is composed of the same minute formative element, has not any determinate shape, but is loosely spread about and between the organs. This is an important tissue; it was formerly known under the name of cellular tissue, but that title is now more properly employed to denote tissues composed of cells.

The areolar tissue is composed of little fibres and plates of membrane, bedewed with a film of moisture, and so connected with each other as to form a loose slim web, with its adjoining meshes opening into each other, so that fluids can pass freely through it. This tissue is continuous in all parts of the body; and thus when air escapes from the lungs through some accident, and gets into the areolar substance, it may spread through the trunk and limbs, causing the whole body to be puffed up; or in dropsy, where watery liquid gathers in the areolar tissue, it sinks downwards by its weight from all parts of the body to the feet and legs, or gravitates to the back in the reclining position.

This tissue forms the medium of union among the organs of the body, being placed between them when moderately free mobility is required, and when too great friction does not exist; it grows plentifully round the great blood-vessels in their course, and fills in the interstices and corners about the bones and ligaments; it is found, in a very delicate shape, between the great muscles of the body and limbs; it forms the bed, where oily matters are lodged in the substance commonly called fat or adipose tissue, and thus forms a sheath beneath the skin over the whole body. Not only is it thus placed about and between the organs, but it commonly, in a more or less perfectly developed form, enters into their structure, still for the same purpose, to hold together and unite their component parts, and blend them into their proper consistence and shape. Its functions in the organism are of low order, being only of a mechanical nature. This form of tissue is in all parts of the body directly continuous with the hard fibrous sheaths or coverings known as fasciæ or aponeurosis, and the fasciæ are generally indefinitely continuous with tendons. The areolar tissue may be regarded as loose aponeurosis, and aponeurosis as dense areolar tissue, in all but the arrangement of the fibrils; for in the aponeurosis the little fibrils are connected to form long fibres, which are interwoven, crossing each other so as to compose a thinner or thicker sheet; whilst such fibrils as in the areolar tissue are disposed irregularly, and in aponeurosis in a woven-like manner, form tendons when placed in a parallel manner in bundles.

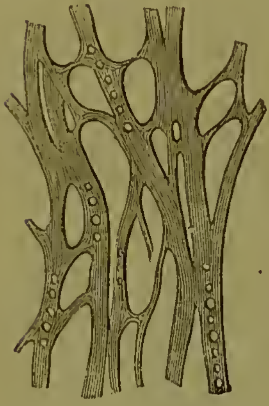
Fat, as it is popularly termed, consists of areolar tissue in whose meshes are lodged clusters of very minute oval vesicles (Fig. 12), fed by blood-vessels which are spread about over and between them. These vesicles are full of a particular kind of oily matter, which is a mixture of a fluid oil called oleine, from being plentiful in the oil of the olive, and a solid fat substance, called margarin, from the pearly appearance it presents when pure.

These substances are mingled in such proportions as to produce, when supported by the containing cells and surrounding web, the proper consistence of the fat of the body at ordinary temperature.

Plentifully as fat is distributed in a well-nourished person, it has in all parts of the body the same structure. It is well known how commonly it disappears under conditions of ill-health. The wasting of the fat is effected by its absorption from the interior of the cells, where its place is taken by a watery fluid.

When we were considering the microscopic structure of areolar tissue we found it composed of wavy tough fibres and cells; there is further, in addition, a small proportion of fibres of an elastic kind, which beneath the microscope are well defined in outline and yellowish in colour, whilst they branch and unite with each other: these are met with in a separate condition in "Elastic Tissue." This substance, in its pure state, is scarce in the body; it is found in the walls of arteries (Fig. 13) in the back-bone, forming ligaments between the spines of the vertebræ; and in some other ligaments it is also present, particularly in the vocal cords, where its elasticity allows the length of them to be increased and lessened. But the most elaborate of the structures which are comprised in the class of connective or mechanical tissue is bone. In this substance, though at first sight it is so unlike the rest, the microscope shows still the fibrous basis here charged with lime salts, and the cellular bodies spread throughout it. These are disposed with great regularity about the numerous blood channels, which form a network in the whole substance. In the composition of bone, as displayed by the highest powers of the microscope (Fig. 14) we discover very minute lamellæ of calcified membrane, grown concentrically round hollow channels (Fig. 15, *a*) which run parallel to each other in the course of the long axis of the bone, so that these channels thus come to have very thick stony walls built up of layers round the central tube; all these hollow channels are short, and end by opening into two or three of their neighbours on either side, so that every one of these channels thus communicates with the rest. The result of this arrangement is to establish a network of hollow channels throughout the bony substance.

Fig. 13.

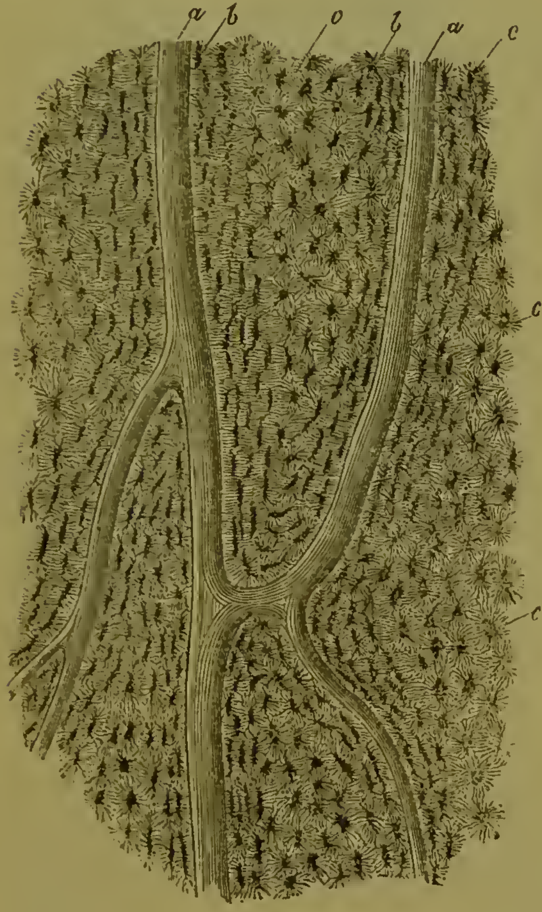


Elastic network, from the *tunica media* of the pulmonary artery of the horse, with holes in the fibres; magnified 350 times.

The network when it reaches the surface, both externally and in the marrow-canal, opens upon it by numerous little orifices, which can be detected with the aid of a pocket lens. The little channels are called Haversian canals, after their discoverer; and when surrounded with their concentric lamellæ they are denominated Haversian systems. When the Haversian canals unite, the surrounding concentric layers also meet and blend together.

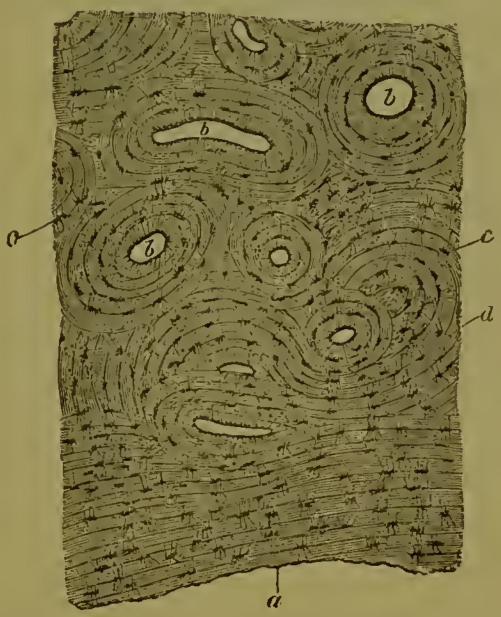
Bone is thus made up of a series of thick-walled communicating tubes, but between their curved surfaces there are necessarily interstices, which are filled up with more of the laminated material, and the whole is thus rendered compact and solid. Between the lamellæ around any Haversian canal are placed, at regular intervals, oval cavities called lacunæ (Fig. 14, *c*), and these oval cavities are flattened between the layers, and from their flat surfaces they give off very fine wavy root-like canals called canaliculi, which pass through the lamellæ and often reach and join the root-like offsets from the neighbouring lacunæ; those from the lacunæ which are nearest to the central canal opening into its in-

Fig. 14.



Section parallel to the surface, from the diaphysis of a human femur; magnified 100 times. *a*, Haversian canals; *b*, lacunæ seen from the side, belonging to the lamellæ of the same; *c*, others seen from the surface, in lamellæ which are cut horizontally.

Fig. 15.



Segment of a transverse section of a human metacarpal bone, treated with concentrated oil of turpentine; magnified 90 times. *a*, inner surface of the bone, with the inner fundamental lamellæ; *b*, transverse section of the Haversian canals, with their lamellar systems; *c*, interstitial lamellæ; *d*, lacunæ and their processes.

terior, whilst those on the outermost part communicate with the canaliculi of the lacunæ of the adjoining Haversian systems. Thus in every Haversian system there is a permeating system of very small channels, connected at intervals with the flattened oval spaces. Any lacuna, with its canaliculi, is occupied by a body which is moulded to it, and fills it exactly, thus taking the shape of a flattened body with projecting filaments; in fact, a ray-bearing cell, such as we meet with in areolar tissue and tendon.

The Haversian canals carry arteries or veins throughout the bone from the surface which is clothed by a membrane rich in blood-vessels, called periosteum, to the interior, which is lined by a much finer and less vascular membrane; the cells of the lacunæ appear to govern and provide for the nutrition of the bony substance in their immediate neighbourhood.

The above account applies in all its details to the hard parts of bones, only it is well known that bones are composed of two sorts of substances; one brittle and solid-looking, the other spongy, with reddish marrowy substance in its meshes. The only difference in the microscopic structure of the two sorts is, that the arrangement of the concentric rings, &c., above described, which is so beautiful in the solid bone, is disturbed in the spongy part; so that we find the lacunæ and canaliculi spread about in plates and columns of the sponge-work, which are generally too small to afford room for a complete Haversian system.

The last-described spongy tissue is called cancellated; it is more abundant than the dense and hard form, and it composes all the more bulky parts of the skeleton; it is found in the enlarged ends of the long bones of limbs, whilst the short and flat bones, as well as the bones of irregular shape, are almost completely moulded out of it, though a deceptive appearance of solidity is produced upon their surface by a thin coating of firm bony material.

By this distribution the longer bones, which afford between their further ends great leverage for fractures under lateral strains, are secured against breakage by the firmness and strength of their substance; whilst in the shorter bones, where there is no fear of lateral strains, the surface of the bone is sufficiently sustained from beneath by the little columns and plates of the cancellated tissue; and these we find so disposed that they run for the most part perpendicular to the surface, especially where, from the position and connexion of the bone, any special pressure naturally falls. In this way the bones are made strong, and yet conveniently light, and in the mean time a most important provision is forecast for by the spreading of the fine solid meshwork throughout the bone, which is else filled with fluid. Any shocks which the bone will receive are dispersed from column to water, and thus their effectiveness for injury is most favourably lessened. In the shafts of the long bones, which, as we said before, are always composed of the hardest material, the provision of lightness is effected by

Fig. 16.

A

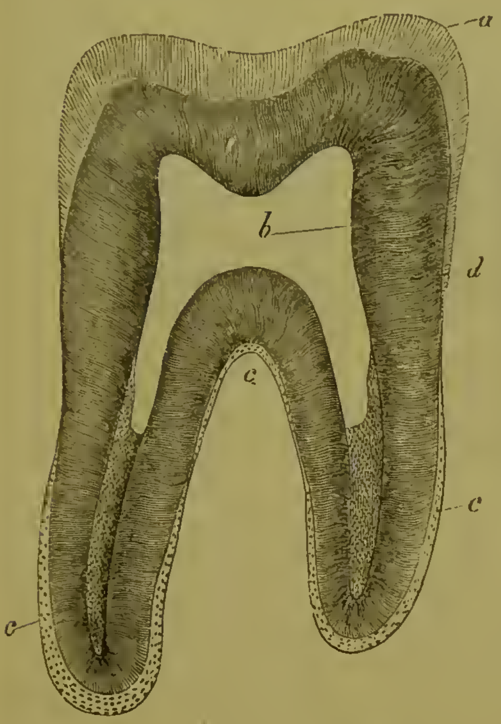
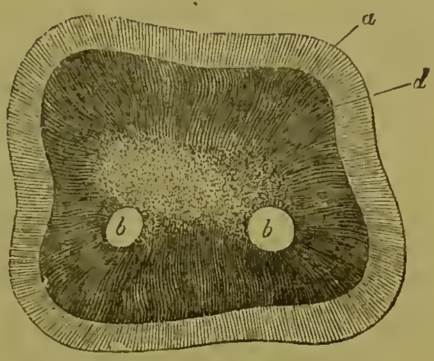


Fig. 17.

B



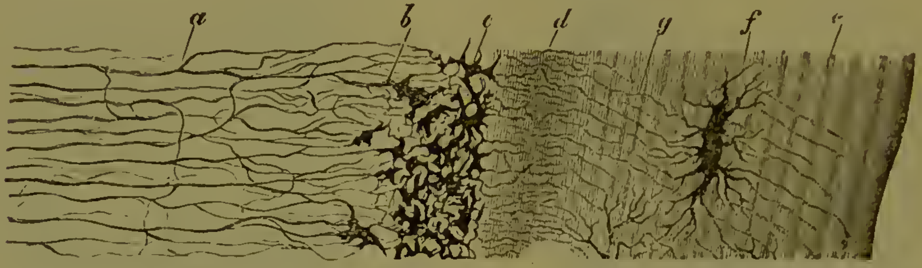
Human molar tooth; magnified about five times. *A*, a longitudinal, *B*, a transverse section. *a*, enamel; *b*, pulp-cavity; *c*, cement; *d*, dentine, with the canaliculi.

the formation of the medullary canal within it; and thus, without loss of strength, increase of surface for the attachment of muscle is afforded.

The ivory of teeth offers us a modification of the osseous structure. Every tooth is composed of three substances (Fig. 17), ivory or dentine, enamel, and crustra petrosa, the stony crust of the fang. Though a tooth is almost solid, it contains a small hollow (Fig. 17, *b*, *b*) in its interior, from which a canal runs down its fang or root, and opens at the end of it; this hollow contains the nerves and nourishing vessels of the tooth, which enter into it by the hole at the end of the fang. The ivory (Fig. 16, *d*) forms the main bulk of the tooth, constitutes its body, giving to it its natural shape; it is covered outside by a coating of either of the other substances, the enamel (Fig. 16, *a*) covering the crown or free part of the tooth, whilst the stony crust (Fig. 16, *c*) covers the fang, which is inserted into the pits of the jawbone. The crustra petrosa is, in its structure, quite like true bone, showing the lacunæ and canaliculi proper to it; but the canaliculi of the crustra petrosa (Fig. 18, *f*, *g*) are apt to assume a direction vertical to the surface of the tooth, and to extend out a very long distance in the crust.

In the dentine we find very numerous fine tubes, with proportionately thick walls, running through a structureless intermediate substance, and all alike radiating from the central cavity towards the surface of the tooth: as they pass along their course is wavy, and they divide (Fig. 18, *a*) and send off branches as they go, until finally they reach the enamel or crustra, where they often end in little cavities, or a few stretch into the substance of the crustra, and there become continuous with the canaliculi of its bony structure. The vessels of the tooth do not extend into these fine tubes, which, like the canaliculi of bone, form a system of fine canals throughout the dentine wherefrom the flow of blood is excluded, but along which a fluid is drawn from the blood-vessels fit and sufficient for the nourishment of the hard tissue in their vicinity.

Fig. 18.



Dentine and cement, from the middle of the fang of an incisor tooth. *a*, dentinal tube; *b*, interglobular spaces, looking like lacunæ; *c*, finer interglobular spaces; *d*, commencement of the cement, with numerous closely-disposed canals; *e*, lamellæ of the same; *f*, *lacunæ*; *g*, *canaliculi*. Magnified 350 times. Of man.

The enamel is constructed of cells, charged with lime: these cells are adherent in rows perpendicular to the surface; the lines themselves are slightly sinuous, and the whole is compacted so closely as to confer on the enamel its adamantine hardness.

CHAPTER VII.

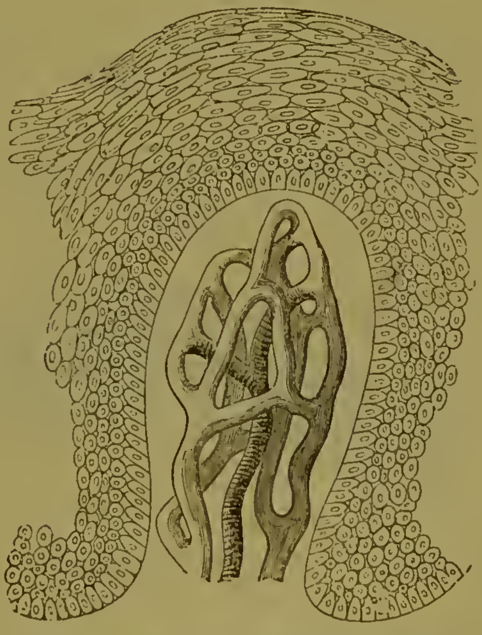
OF CUTICLE.

All the free surfaces of the body, external or internal, are protected by a tegument composed of cells, which being itself devoid of blood-vessels and nerves, forms an insensible inert covering, that is fitted to come into contact with extraneous bodies without injury or pain.

On the exterior surface of the body it forms the scarf-skin, cuticle, or epidermis, the true skin or dermis, with its rich supply of vessels and nerves, being under it. The cuticle-cells grow upon the delicate basement membrane which bounds the surface of the true skin: they originate close to this membrane, in the deeper part of the cuticle, and then are borne towards the surface by the production of other younger cells beneath them, whilst the older cells on the exterior die, and are rubbed off during contact with whatever may happen to touch the body.

When the cells are young and deep-seated, they lie separate from each other, and are albuminous in their composition, and delicate in their texture; but as they grow older, they change in shape, first coming in contact with their neighbours all round, so as to be flattened on as many sides as there are contiguous cells: as they increase in age, and progress towards the surface, they become firmer, and even horny in texture; whilst they now are composed of gelatine chiefly: at the same time they flatten out parallel with the surface, meeting at their edges; the cavity of each is obliterated and their vitality lost; at length they lose their mutual cohesion, and are worn easily off by the touch of any ordinarily rough substance.

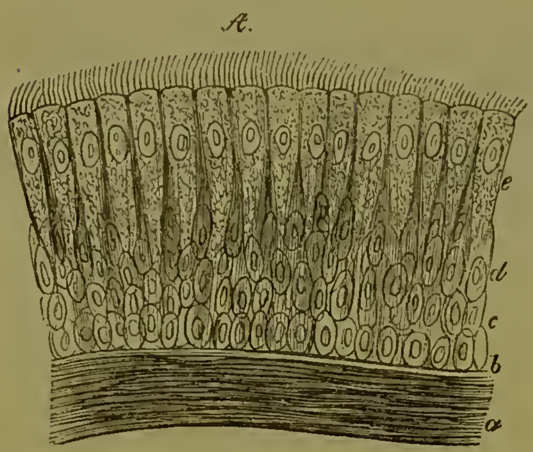
Fig. 19



A simple papilla, with several vessels of epithelium, from the gums of a child; magnified 250 times.

It is not alone upon the exterior of the body that such a covering is found; all the cavities and passages within the body are lined by a tegument of the like structure (Fig. 19), which, however, is softer and thinner than the cuticle of the skin. It is only when friction is to be provided against, that the flattened "pavement" cells just described are grown; the smooth shining serous membranes, which line the cavities that contain the viscera, and cover the viscera which those cavities contain; the interior of joints; the inside of the arteries and veins; the mouth, &c., are protected by such a covering of pavement cuticle, which is called epithelium when it is placed on the interior surfaces.

Fig. 20.

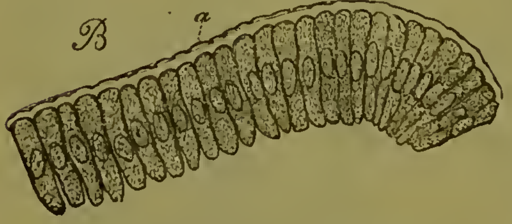


Ciliated epithelium, from the human trachea; magnified 350 times. *a*, innermost part of the elastic longitudinal fibres; *b*, homogeneous innermost layer of the mucous membrane; *c*, deepest round cells; *d*, middle elongated; *e*, superficial, bearing cilia.

The air passages are the chief seat of a beautiful form of cuticular lining (Fig. 20), whose cells do not flatten as they grow towards the surface, but elongate, and take the shape of columns compressed at the sides by their neighbours: they are attached by one end, and at the other furnished each one with a multitude of little fleshy hairs called cilia, which during life are in incessant motion. This motion, by some mysterious agreement, is so governed, that the hairs in moving bend sharply down all in the same direction, and raise themselves more gently to repeat the act: this direction is upwards along the air tube, so as to waft particles of dust, or excess of secretion, towards the mouth. (See Fig. 81).

The cuticular lining of the alimentary canal (Fig. 21) is formed of cells, whose shapes, like the last, are columnar, but they are devoid of vibratile cilia.

Fig. 21.



Epithelium of the intestinal villi of the rabbit, magnified 300 times.

The secreting glands are formed on a simple plan: in the construction of any of them a tube opening on the surface is at the other end, either simply closed, as in the minute sweat-glands and the microscopic gastric tubules that pour out the digestive juice, or else, as in the greater glands, such as the pancreas and salivary glands, the tube—called duct—is divided, and subdivided, and divided again, until its divisions become a vast number and excessively fine: the fine divisions end in closed dilatations, and around these is spread a rich network of blood-vessels, which furnish the matters that form the secretion of the gland.

These matters are collected from the blood by the action of epithelial cells of the 4th class, which form a lining to the tubes and their ends. In the finest tubes and their terminal dilatations, where the secreting power resides, the cells which exercise this power offer the most characteristic examples of this form of epithelium, and have a polygonal shape, which is identical with that of the younger stages of other epithelial elements.

CHAPTER VIII.

OF THE BLOOD.

The blood is a thick, viscid, tenacious fluid, somewhat heavier than water, slightly alkaline, clammy to the touch, saltish to the taste, of a peculiar faint odour and red colour, scarlet red in the arteries, and purple in the veins.

It is commonly called, by way of distinction, the circulating fluid, though other fluids move in a definite direction, as the chyle, which flows from the small intestines to the thoracic duct, but it is the only fluid that describes a circle.

To the naked eye it appears homogeneous; when examined with the microscope, it is seen to consist of a transparent colourless fluid, with minute solid particles floating in it. The clear fluid is called the liquor sanguinis. The solid particles are of two kinds, one red, to which the red colour of the whole mass is due, and the other colourless; the former are called the red, and the latter the lymph particles, or cells.

Immediately after blood is drawn from its vessels it undergoes a very remarkable change. First, an aqueous vapour arises from it, having a peculiar faintish odour, disagreeably perceptible on passing a slaughter-house: then a thin film is formed upon its surface, which is soon followed by the conversion of the whole mass into a soft jelly. As the jelly solidifies, a fluid begins to ooze from it, and the jelly itself further separates into two parts, one a yellowish substance, occupying the upper, and the other a red mass at the under surface.

In this manner a natural dissection of the blood takes place, by which it is resolved into its constituent parts. The process by which this is effected is termed coagulation, and the several constituents of the blood thus separated from each other are—the fluid portion, the serum; the solid part, the coagulum or clot; the yellow substance, the fibrin, the portion on the surface of the clot; and the red and lymph particles forming the red mass at the under surface.

Coagulation probably commences the moment the blood leaves the vessels. In three minutes and a half it is visible to the eye; in eight minutes the mass is formed into a jelly; in from twelve to fifteen minutes the serum separates from the clot; and in about twenty minutes the solidification is complete, but the clot continues to grow firmer and firmer for some hours.

Many circumstances influence the rapidity and completeness of this process. It commences the earlier, and is sooner completed, when the abstraction of blood is rapid, and also during the prevalence of diseases of excitement. But the process is less perfect the more rapidly it is performed, the clot being proportionably more bulky and less firm, and the serum less completely expressed from it. Arterial coagulates more quickly than venous blood, and the blood of women begins to coagulate nearly two minutes sooner than that of men.

Copious and repeated blood-letting, which rapidly exhausts the vital powers, quickens, in a striking manner, the process of coagulation. In blood taken from the arm of a woman labouring under fever, the portion first effused remained fluid seven minutes; a similar quantity taken immediately before tying up the arm was coagulated in three minutes and thirty seconds.

When blood is effused within the body, as from the rupture of a blood-vessel, coagulation takes place just as it does when it is drawn from a vein, and this is of the greatest importance in checking hæmorrhage; for the tendency to coagulation, as just stated, increases with the diminution of the vital powers, and so the fainting caused by the loss of blood favours the suppression of the bleeding by stopping the mouths of the bleeding vessels with a solid substance.

There is not a perfect agreement as to the true nature of coagulation. The general opinion is that it is a process of organisation; the first step towards the formation of organised structure; for the fibrin of a clot, when blood is effused within the body, always disposes itself into delicate threads, or fibrillæ, thus taking a definite form, and presenting, as is thought, the rudiment or basis of definite structure. No vessels can at first be seen in the fibrin, but after a time they make their appearance, generated, as some think, in the fibrin itself; or, as others believe, continued from neighbouring vessels: in either case the fibrin itself is now organized, and is capable of being subsequently converted into tissues and organs. Out of the body, however, some regard the process as one of death, rather than life, as the mode in which the blood breaks up and becomes disorganized.

There are conditions under which the blood will not coagulate, as after profuse hæmorrhages in malignant fevers, after exhaustion from excessive muscular exertion, as in hares after coursing, and in death from lightning.

The constituents of the blood obtained from its spontaneous coagulation are, then, serum, fibrin, and red and colourless particles. But the blood, as it circulates in the living body, is a still more complex fluid, and consists of—

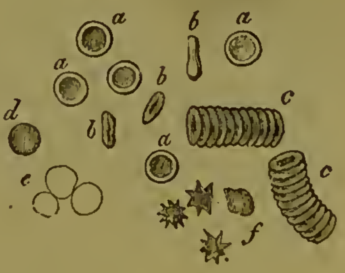
Liquor sanguinis.
Serum.
Albumen.
Fibrin.
Red and colourless particles.
Oily, fatty, and extractive matters, and saline substances.

Liquor sanguinis.—This, as already stated, is the fluid part of the circulating blood before coagulation has taken place. It holds in suspension the solid particles which float freely in it. In the process of coagulation the fibrin, which is dissolved in the liquor sanguinis, separates and becomes solid, the remaining fluid is then called—

Serum.—The fluid which oozes from the clot during coagulation. When poured from the clot, and obtained perfectly pure, it is of a light stone colour, tinged with green; its taste is saline; its consistence adhesive, from its holding animal and saline matter in solution; and its specific gravity varies from 1025 to 1030. At a temperature of 160° it parts with albumen, which is thrown down as a white, opaque, solid and firm substance; and this is also obtained by the application of spirits of wine, acids, particularly the nitric, bichloride of mercury, and other chemical agents.

It varies from 60 to 70 parts in the 1000 of the blood. It is derived immediately from the food; fresh supplies of it from this source being constantly poured into the blood. It is of the highest importance in the living system, as introducing into it the consolidating material of bones, by its power of uniting with phosphate of lime.

Fig. 22.



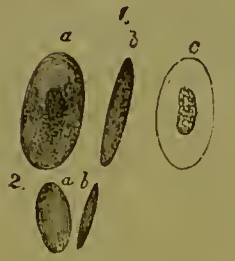
Human blood-globules; *a*, seen from the surface; *b*, from the side; *c*, united in rouleaux; *d*, rendered spherical by water; *e*, decolourized by the same; *f*, blood-globules shrunk by evaporation.

Red particles (Fig. 22. *a*, *b*).—These are true cells, and possess essential cellular structure. They are not properly globular, but rounded flattened discs, having circular and very slightly-thickened margins; the thickness of the margin giving to both surfaces the appearance of a slight depression in the middle, so that the particles bear a close resemblance to a penny piece. They are biconcave discs. They are composed of a delicate, pellucid, membranous cell wall, which encloses the contents of the cells. They are seen under the microscope to be of different sizes, but the greater number are of the same uniform magnitude. They range from the $\frac{1}{3000}$th to $\frac{1}{4000}$th of an inch in diameter, and are about $\frac{1}{1000}$th of an inch in thickness. They are of a soft and yielding nature, for they alter their shape on the slightest pressure, as is beautifully seen when they are in circulation, elongating, or contracting, and altering their shape in various ways to accommodate themselves to the vessels, and they are very elastic, for they recover their natural shape the moment they escape from compression.

There is, at least in the human blood-cell, no distinct nucleus. The cell contents consist of exceedingly fine granular particles, composed of two distinct substances: one colourless, allied to albumen, termed globulin; the other a colouring principle, termed hæmatin, communicating colour to the cell. The hæmatin contains nearly ten per cent. of iron, which is supposed to be united with it in the state of oxide, just as the salts are combined with albumen. When the iron is entirely separated from the hæmatin, the latter imparts an intensely red colour to alcohol; the red colour of the blood, therefore, cannot be due to iron, as was long supposed, but is inherent in the colouring principle itself.

The above description of the blood-cells is applicable only to the mammalia, and particularly to man. In birds, reptiles, and fishes, the red particles are not round but oval, with a central elevation on both surfaces (Fig. 23). They are larger in birds than in mammalia, and largest of all in reptiles. In the proteus, for example, they are $\frac{1}{327}$th part of an inch in diameter, almost visible to the naked eye. The size of the blood-cells is not in proportion to the size of the body.

Fig. 23.

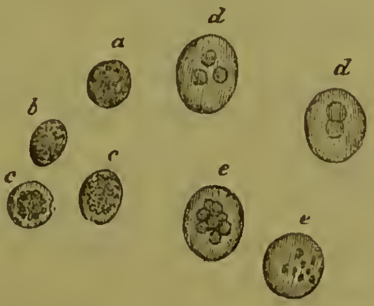


1. Blood-cells of the frog. *a*, seen from the surface; *b*, from the side; *c*, decolourized by water. 2. Blood-cells of the pigeon. *a*, seen from the surface; *b*, from the side.

The red particles form by far the largest part of the organic matter of the blood. They are notably different in quantity in the two sexes, being in men from 116 to 148 parts in 1000; in women from 68 to 130 parts. They also vary considerably according to temperament. In men of sanguine temperament they are about 136 in 1000, in women about 126. In the lymphatic temperament in men 116, in women 117. They are in greatest abundance from 30 to 40 years of age, and they diminish much as old age advances.

Colourless, or lymph cells (Fig. 24).—These are nearly globular in shape. They are fewer in number than the red, the proportion being as 1 to 50. They are larger in size, about $\frac{1}{2500}$th of an inch in diameter; they are specifically lighter; in the circulating fluid, they always float at the sides of the current, the red cells keeping in the middle: they are constantly poured into the blood by the chyle and lymph, and when they enter the blood, they either pass into the higher form of red particles, or perform some special office and then perish. The general opinion is that they form the red particles by a successive process of evolution and transformation; passing progressively from a globular shape, the primitive one of all organic cells, to a flattened and elliptical form, their contents being gradually converted into the peculiar matter contained in the red cells.

Fig. 24.



Colourless blood-corpuscles, or lymph-corpuscles of the blood. *a*, *b*, smaller cells, such as also occur in the thoracic duct, seen from the surface (*a*), and on the side (*b*); *c*, *c*, the same with a visible nucleus; *d*, *d*, large cells originally with multiple nuclei; *e*, *e*, the same after the action of acetic acid, with breaking down or broken-down nucleus.

Oily and fatty substances.—Generally estimated at about 6 parts in the 1000. They are derived immediately from the food. Their chief use is to support combustion, and to supply the fatty matter required in the composition of nervous substance.

Extractive matters.—Little is known of their precise nature. They include certain animal substances in a state of change, which are not eliminated from the blood by the processes of excretion.

Saline matters.—Constitute about 6 parts in the 1000. Consist chiefly of chlorides of sodium and potassium, but several other substances, earthy and animal, are also found in minute quantity.

Their use is to prevent the decomposition both of the blood and of the substances that are formed out of it; to maintain the fluidity of the fluids, and the solubility of the solids, and to supply the earthy and mineral materials required in the system.

Arterial and venous blood.—Arterial blood contains less carbonic acid than venous in the proportion of from 20 to 25 per cent. of its volume; a little more hydrogen, less albumen, and more fibrin; a greater number of red cells, and, above all, it is distinguished by its bright scarlet colour, as contrasted with the dark purple of venous blood.

Proportion of solid matter in the blood.—Taking together all the solid substances contained in the blood, they form from 200 to 210 parts in 1000.

Specific gravity of the blood.—It must, therefore, be of greater specific gravity than water, the average in health being from 1050 to 1055, or perhaps 1059. The specific gravity is somewhat greater in men than in women, on account of the greater number of red particles in the former; while the quantity of albumen and fibrin is pretty much the same in both.

It is essential to the integrity of the blood that the relative specific gravity of its several constituents should be maintained up to a certain point; for if the liquor sanguinis, for example, were not always sustained at a given density, the red cells would immediately lose their structure, their contents would be drawn out of them by exosmose, or they would imbibe water by endosmose, swell up, become globular, and ultimately burst.

Temperature.—No vital process can go on in the animal blood after its temperature falls below a given point. The temperature of the human body ranges in health from 96° to 99°. The mean is about 97° or 98°. This degree of heat is maintained with surprising uniformity under all the diversified circumstances and conditions in which the human body may be placed.

It varies but very slightly at the equator and at the poles, but it is a little higher in some organs than in others. Thus, in the ventricles of the heart, it is generally 101° or 102°, and it is from 1° to 2° higher in the left than in the right ventricle. Fluids examined immediately after having been passed from the body, are generally found about the temperature of 101°.

Quantity of blood in the body.—It is impossible to determine the absolute quantity of blood in the body, because, after every effort to remove it from the vessels, a portion must remain in the tissues. Suppose that the circulation is completed in two minutes, that there are 75 pulsations in a minute, and that 2 ounces (troy) are propelled from the heart at each pulsation, this would give 25 pounds of circulating blood. Haller estimated it at 28 pounds, which in a man of ten stone would be one-fifth of the weight of the body, and this is generally considered as pretty near the truth.

Relative quantity of blood in the organs.—This entirely depends on their activity; they must, therefore, present great variations. The belly of a muscle, which is its active part, is quite filled with blood, and is consequently of a deep-red colour, while the tendon, which is merely to convey the result of contraction, being itself passive, has so few vessels that it is nearly white.

The organs, arranged according to the quantity of blood they receive, stand in the following order:—

1. Lungs, which receive the largest amount, but not for their own use, the greatest part being for the aëration of the blood.
2. Glands or secreting organs.
3. Heart, which is always at work, and must, therefore, receive a large supply of blood to obtain the necessary nourishment; it must be replenished with adequate material to supply its waste.
4. Grey matter of the nervous system.
5. External skin, and internal mucous membrane.
6. Fleshy belly of muscles.

7. Nerves.
8. Bones.
9. Tendons.

There are a few parts which seem to receive no blood-vessels at all, and which are, therefore, said to be extra vascular, as the cuticle or scarf skin, nails, hair, horn, and cartilage.

Demands for blood.—In the living system there is a constant demand for fresh supplies of blood.

1. To sustain the molecular change which is incessantly going on in the body—that is, to afford materials for the repair of waste.
2. To furnish the materials for growth.
3. To afford the materials for secretion.
4. To maintain animal heat.
5. To afford the requisite stimulus to the muscular system and the nervous centres.

Sources from which the blood is renewed.—These are—

1. The chyle, prepared by the process of digestion from the food.
2. The contents of the lymphatic vessels.
3. Liquids absorbed directly from the stomach by the veins.
4. Gaseous substances introduced into it as it circulates through the lungs.

From the preceding account, it is evident that the blood contains in it all the materials necessary for nutrition, either as elements, or as substances already formed, and capable of numberless transformations, and of being ultimately converted into tissues and organs.

The blood composed of the most heterogeneous matters is as truly organised as any organ that is formed out of it, all its constituents having definite properties existing in definite proportions, and bearing definite relations to each other, none of which can be changed except within narrow limits, without impairing its structure and disturbing its functions.

Provision is made, in the fundamental constitution of the blood, for the maintenance of the due balance between all the parts of the body. If, for example, the fluid parts are deficient, thirst is produced: part of the fluids taken into the stomach, as water, tea, wine, and the like, pass directly into the blood by venous absorption, until the equilibrium is restored, and if there be no means of accomplishing this by drinking, rapid absorption takes place by the skin and lungs. If, on the other hand, the solids are deficient, hunger is excited: the gratification of appetite introduces food into the stomach; rapid digestion commences with predisposition to rest and sleep, and during this state of the system it is placed under the most favourable conditions for the production and deposition of the new substances required.

Since the chief source from which the blood is replenished is chyle formed from the food, it is obvious that too much or too little food, or too great or too little activity of the organs that digest it, may render the quantity of the blood, absolutely or relatively, too abundant or deficient; while its quality may be vitiated by a disturbance in the balance of the circle of organs engaged in nutrition, as digestion, respiration, absorption, secretion, and so on. By the processes carried on by some of these organs, essential constituents of the blood are withdrawn from it; by others, hurtful ingredients are poured into it, for the removal of which, organs called depurating are provided, as the lungs, liver, kidneys, and the like. If the lungs fail to eliminate carbon; the liver bile; the kidney urea; carbon, bile, urea, must accumulate in the blood, contaminate it, and render it incapable of duly nourishing and stimulating the tissues and organs.

But the blood is capable of being directly and fatally poisoned by external agents, with which it is of the highest practical importance to be acquainted. Liquids, as has been just stated, are immediately absorbed into the blood by minute vessels on the surface of the stomach; gaseous substances enter into and pass out of the blood through vessels spread out in the air-cells of the lungs.

These imbibing vessels are wholly unguarded against gaseous substances; they exercise no choice; they are capable of none; they take up equally whatever substances are presented to them, whether noxious or salubrious. Hence the most deleterious matters find unchecked entrance into the blood. Water holding poisonous substances, in solution or suspension, conveys them into the blood almost as soon as swallowed. Poisons suspended in the atmosphere enter the blood by every act of breathing, and are instantly diffused through the system. Noxious gases exhaled from cesspools or from the human body itself in overcrowded and unventilated dwelling and sleeping rooms, enter the blood by the same short route, and poison it with the same rapidity. When these poisons are concentrated the effects are instantaneous, and death is caused by a few respirations, instances of which occur every year in London and Paris. Under ordinary circumstances, the mischief is slow in its operations, and the true agent is often unsuspected, and it may be denied; but it is not the less active and powerful because it is unrecognized; and however its influence on individual and on public health may be doubted or disregarded in the present state of popular knowledge, it can hardly fail to be appreciated when the mechanism and action of the organs, which the Creator has made the safe-guards of life, are understood.

CHAPTER IX.

OF MUSCLE.

Muscular Tissue.—Muscle, or flesh, is endowed with the property of contractility, that is, the power of shortening itself. This power is the exclusive source of all proper animal motion.

The muscles of the body, taken together as a whole, are divisible into two great classes, according as they are or are not under the control of the will. We move from place to place by muscles which are put into action by an effort of volition; but the heart beats, and the food is forced along the alimentary canal by muscles over which the will has no control. The first set of muscles is termed *voluntary;* it comprehends principally the muscles which are concerned in locomotion: these are proper to the animal life. The second set is termed *involuntary;* it includes the muscles which are concerned especially in carrying on the internal operations of the system: these are proper to the organic life. There is good ground for this distinction, which is a broad and very convenient one: but it does not hold invariably; for there are muscles which partake of both characters, being affected by powerful emotions of the mind, while they are still not under the direct influence of the will.

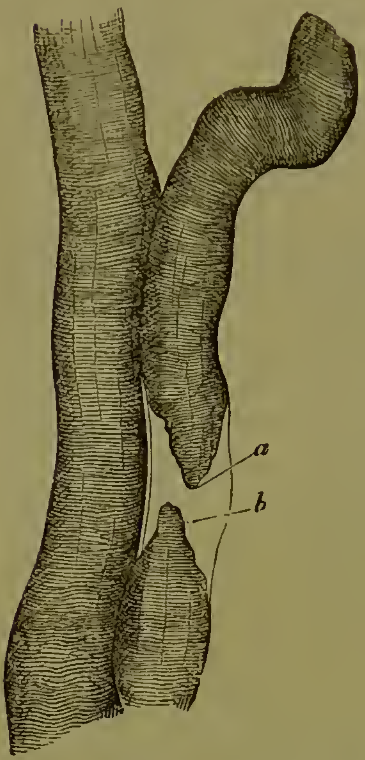
Whatever may be the difference between voluntary and involuntary muscles in their office, they do not present to the naked eye any very marked difference in their appearance; yet there is really as great a difference in their structure as in their function. We owe our knowledge of their intimate organisation entirely to the microscope. Without this invaluable aid to science, the curious and interesting facts now to be described could never have been known.

On examining a voluntary muscle under a high magnifying power, its appearance is very striking. It is seen to be marked by a vast number of alternate light and dark lines (Fig. 25). On examining an involuntary muscle under the same power, no such markings are apparent. The first set is, therefore, termed the *striped,* and the second the *unstriped* variety.

Yet it is remarkable that the heart, though not under the control of the will, is composed of the striped variety of fibres. We have seen that the distinction between voluntary and involuntary muscles is not absolutely universal.

Unstriped Variety of Fibres.—These consist of flattened bands of a pale colour. They differ very remarkably from the striped variety; as their name implies, they are without the peculiar markings of the latter. They appear to be destitute of sarcolemma.* They often seem to interlace with one another, but this is regarded as a deceptive appearance. On careful examination it is found that they do in fact all run parallel. They are peculiar to the organs of organic life, which, as has been stated, are for the most part hollow, as the stomach, the intestines, the bladder, and the uterus. They are distributed over these organs as a circle more or less complete; where one passes only partially around, the rest of the circle being completed by others. Their ordinary diameter is from $\frac{1}{3000}$th to $\frac{1}{2000}$th of an inch.

Fig. 25.



Two human muscular-fibres, magnified 350 times. In the one the bundle of fibrillæ (*b*) is torn, and the sarcolemma (*a*) seen as an empty tube.

1. *Intimate Structure of the Voluntary or Striped Variety of Muscles.*—When a fibre taken from a muscle belonging to this class is carefully examined under a high magnifying power, first, the sarcolemma is distinctly seen enveloping the tender sarcous substance (Fig. 25, *a*). Secondly, there are brought into view innumerable dark lines, whose delicacy and regularity cannot be surpassed. These dark lines take a transverse direction across the fibres (Fig. 26); other lighter coloured ones take a direction lengthways to the fibre (Fig. 26). These lines are not superficial; they penetrate through the entire substance of the fibres. Each set of lines would, therefore, appear to divide the fibres into portions. The portions which lie between the transverse lines have received the name of discs (Fig. 26); those which take a longitudinal direction, presenting an appearance of minute threads, are called fibrils (fibrillæ) (Fig. 27). By careful management, these fibrils may be isolated, and the cause of the appearance of transverse bands is then found out, for the little fibril is seen to be made up of similar cubical particles, that so refract the light in their middle part as to produce a dark spot under ordinary circumstances: then, when many such dark spots lie on the same level, as they always do in the fibre, they give rise to a dark line: of course to produce such line, the adjoining

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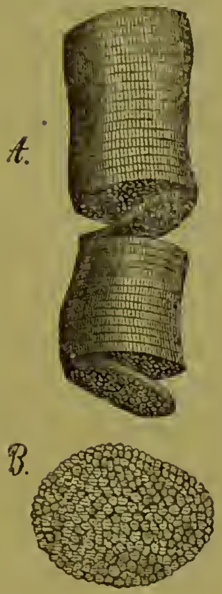
* See p. 65.

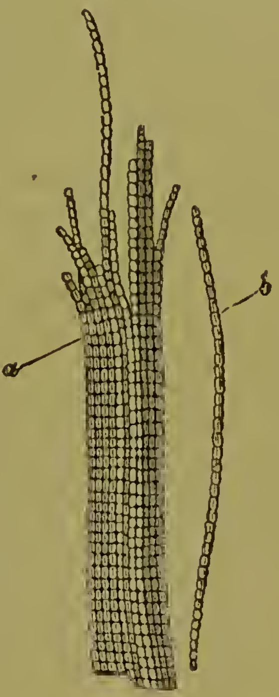
fibrils must have their dark centred cubes just on the same level. Thus, the fibrils, or the discs, consist of parts precisely alike; in the former case arranged in lines, in the latter packed together in planes.

Fig. 26.



A, a muscular fibre, or primitive fasciculus, breaking up in the transverse direction, into discs, 350 times magnified. It exhibits distinct transverse and fainter longitudinal striæ. The discs, of which B represents one more magnified, are granulated, and consist of the sarcous elements of Bowman, or, according to other authors, of small pieces of the fibrils. (After Bowman.)

Fig. 27.



Primitive fibrils from a fibre, or primitive fasciculus, of the *Axoloti* (*Siredon pisciformis*); 600 times magnified. *a*, a small bundle; *b*, an isolated fibril.

"To detach a fibril entire is to remove a particle from every disc, and to take away a disc is to abstract a particle of every fibril." These little cubical particles are called "sarcous elements," and are surprisingly constant in their magnitude in creatures of every size; they are as small in the elephant as in the microscopic rotifer. They are united with each other as they lie side by side in the fibres, and the fibre itself is enclosed in a fine, transparent membrane allied to the basement membrane (Fig. 27, *a*). It is of extreme tenuity, but very tough and elastic. It forms for the fibre a sheath, or rather a perfect tube, in which the tender sarcous matter is lodged, and by which it is sustained, protected, and isolated from all other substances. The nature and office of this membranous tube are expressed by its name. It is called *Sarcolemma*, from two Greek words signifying flesh, and bark or tegument, because it encloses the fibre of the muscle just as the bark encloses the trunk of a tree.

Among the sarcous elements are always to be discerned a number of corpuscles, which are conceived to be the nuclei of the cells from which the fibre is developed. Fibres, unlike the sarcous granules of which they are composed, vary much in bulk. The smallest fibres to which a mass can be reduced take the name of *primitive* or *elementary fibres.*

These primitive or elementary fibres are in general large enough to be visible to the naked eye; but, as just stated, they differ considerably in size in the different classes of animals, and even in different parts of the same animal. They are smallest in birds, and largest in fishes, in some tribes of which, as in the skate, they are of the size of a small pin. In mammalia they are of an intermediate size, between that of birds and fishes. They are larger in man than in any other class of mammalia. Their average width in the human subject is about the $\frac{1}{400}$th of an inch; in the male $\frac{1}{350}$th, in the female $\frac{1}{450}$th. In the human female their average diameter is upwards of one-fourth less than in the male. The absolute size of the fibres appears to be much more intimately connected with the endurance of their irritability than with their direct power. Thus they are largest where their irritability is most enduring, as in crustacea, fishes, and reptiles; and smallest where it is most evanescent, as in birds.

In very minute and simple beings one single fibre, enclosed in its sarcolemma, may perhaps constitute an entire organ; but in general this is not the case. In all the higher classes the primitive fibres are aggregated into masses. They are packed in sets, often containing ten, twenty, thirty, or more. These are united into larger sets, and these again into still larger, until, in muscles of great magnitude, the entire muscle is composed of thousands, and even hundreds of thousands of individual fibres. These packets are placed close and parallel to each other.

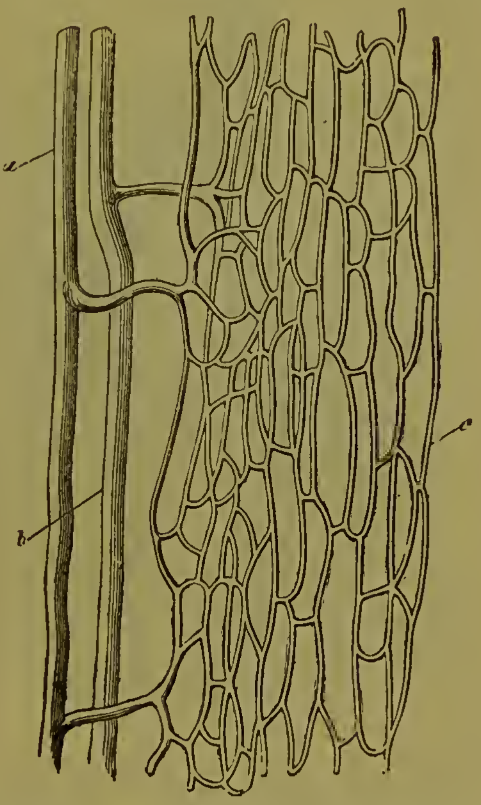
Such is the arrangement of the elementary fibres in the complex mass that forms the basis of a muscle; but in order to complete the composition of a muscle other tissues are superadded to the elementary fibres, either for their nutrition, for their mechanical connection and support, or for their more easy and effective action. The superadded tissues are the areolar tissue, the white fibrous tissue, and blood-vessels, nerves, and absorbents. The organ termed a muscle is the result of all these parts united together.

It is by these secondary, or superadded tissues that the complete organ is rendered sufficiently firm and cohesive for the performance of its office, notwithstanding that its active and essential part consists of a soft and tender pulp.

SUPERADDED TISSUES.

Areolar tissue.—A fine areolar tissue is freely distributed to the fibres, both of the striped and the unstriped variety, but by much the most abundantly to the striped. It has been shown that in aggregating to form a muscle, the fibres are collected into smaller and larger packets. For these packets the areolar tissue often forms an external investment, and even sends septa into the intervals between them. The different packets are capable of acting independently of each other; and on watching carefully a muscle in motion in a living animal, it is seen that some of the packets are in active contraction while others are at rest. The areolar tissue, in which the different packets are enclosed, enables them to move independently of each other, and thus facilitates the performance of their function. The density of these general and partial sheaths is proportioned to the amount of the pressure to which the individual muscle may be subject. The entire muscle is often included in areolar tissue, and is always supplied with nerves and blood-vessels of large size and great abundance.

Fig. 28.



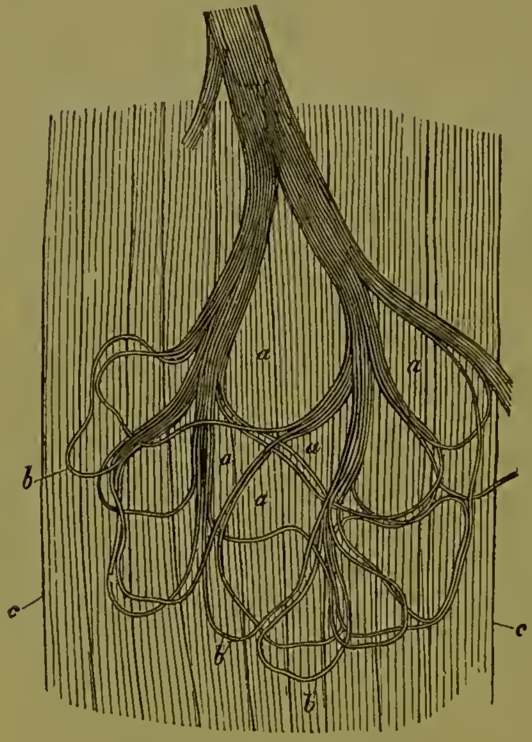
Capillary vessels of muscles, magnified 250 times. *a*, artery; *b*, vein; *c*, capillary network.

Blood-vessels.—Muscular tissue, as just stated, is abundantly supplied with arteries and veins. These commonly run together, there being generally two veins to one artery. The larger trunks pass more or less directly across the fibres. They divide and subdivide, first in the intervals between the larger packets, then between smaller sets, and, lastly, the ultimate twigs insinuate themselves between the fibres composing the smallest bundles, where they break up into their terminal or capillary branches (Fig. 28). The capillaries unite together, open freely into each other, and by their interlacements they form a delicate elongated net-work.

Nervous tubules pass, like the vessels, between the different packets of fibres, following the course of the capillaries, to the smallest packets. They touch the sarcolemma, but they never penetrate it, so that the fine sarcous matter is as completely guarded from the direct contact of nerves as from blood-vessels. Though the nerves accompany the blood-vessels they do not follow them in their last windings, for they terminate in a different figure (Fig. 29). They end, not in points, but in loops. They are much smaller than the smallest primitive fibres, and therefore one nervous loop must carry the nervous influence to many muscular fasciculi. The anatomical relation between the nerves and the muscular fibres is thus very completely made out; their physiological relation is much less perfectly known; yet, to a certain extent, that relation has also been clearly developed. This will be more fully shown when an account is given of the structure and function of nerves.

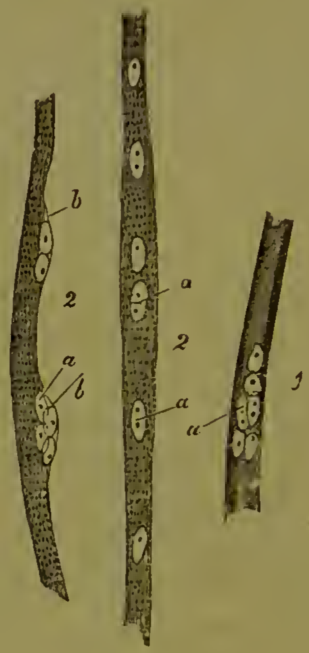
Tissue, in its earliest stage of formation, is seen to consist of a mass of nucleated cells, which first arrange themselves in a linear series, and then unite, to constitute the primitive or elementary fibres. As this union of the cells goes on, a deposit of solid matter—contractile material—gradually takes place within them, commencing in the inner surface, and advancing towards the centre, until the whole is solidified. As soon as solid matter is deposited in the cells, indications of a regular arrangement of the granules are apparent. It is common for the longitudinal lines to become well defined before the transverse ones. Both are always strongly marked at birth. When the nuclei of the cells, which were before visible, disappear, they can still be shown to exist by immersion in a weak acid, which swells the

Fig. 29.



Terminal expansion of the nerves from a human *omo-hyoideus*, magnified 350 times, and treated with caustic soda. *a*, meshes of the terminal plexus; *b*, terminal loops; *c*, muscular fasciculi.

Fig. 30.



Muscular fibres from a human embryo four months old, magnified 350 times. 1. A fibre with a clear, still-unstriped substance in its interior. 2. A fibre without such a substance, and with indications of transverse striæ; *a*, nuclei; *b*, sarcolemma.

fibrinous materials of the granules, and obliterates their intervening lines, but has no action upon the nuclei. It will be remembered that these curious phenomena are in perfect analogy with those of cell-formation in general.

Figure 30 illustrates the development of the striped muscular fibres.

Besides the foregoing substances, all of which invariably enter into the composition of a muscle, every fibre is attached by its extremities to white fibrous tissue, or to some tissue analogous to it. The fibre appears to end by a perfect disc, and with the whole surface of this disc the fibrous tissue is connected and continuous. The fibrous termination of a muscle is termed *tendon*, the various and important uses of which will be explained hereafter.

CHAPTER X.

MECHANISM OF THE TRUNK AND LIMBS.

THE term organisation is employed in reference both to the component parts of the body, and to the body considered as a whole. We speak of an organised substance and of an organised body. An organised substance is one in which there is not only a definite arrangement of its component parts (structure), but in which the particular arrangement is such as to fit it for accomplishing some special use. Every organised substance is therefore essentially a special organ; limited in its object it may be, and perhaps only conducive to some further object; but still its distinctive character is, that it has a peculiar structure, fitting it for the accomplishment of some appropriate purpose. On the other hand, an organised body is a congeries of organs—the aggregate of the individual organs. Attention was directed in the early part of this work to one peculiar and essential character, by which such an organised is distinguished from an unorganised body. Between the individual parts of the organised body there is so close a relation, that no one of them can be removed or injured, or in any manner affected without a corresponding affection of the whole. The action of the heart cannot cease without the cessation of the action of the lung; nor that of the lung without that of the brain; nor that of the brain without that of the stomach; in a word, there is no organ in whatever distant nook of the system it be placed, or however apparently insignificant its function, that is not necessary to the perfection of the whole. But into whatever number of portions an unorganised body may be divided, each portion retains the properties of the mass, and constitutes in itself a perfect existence; there being no relation between its individual parts, excepting that of physical attraction: on the contrary, each component part of an organised body, being endowed with some appropriate and specific power, on the exercise of which the powers of all the other parts are more or less dependent, the whole must necessarily suffer if but one part fail.

From the whole, then, we see that the human body is a congeries of organs; that those organs are constructed of a few simple tissues.

But though by the analysis of its component parts, this machine, so complex in its construction, and so wonderfully endowed, may be reduced to this state of simplicity; and although this analytical view of it be highly useful in enabling us to form a clear conception of the nature of its composition; yet it is only by considering its individual parts such as they actually are, and by studying their situation, connection, structure, and action, that we can understand it as a whole, and apply our knowledge of it to any practical use.

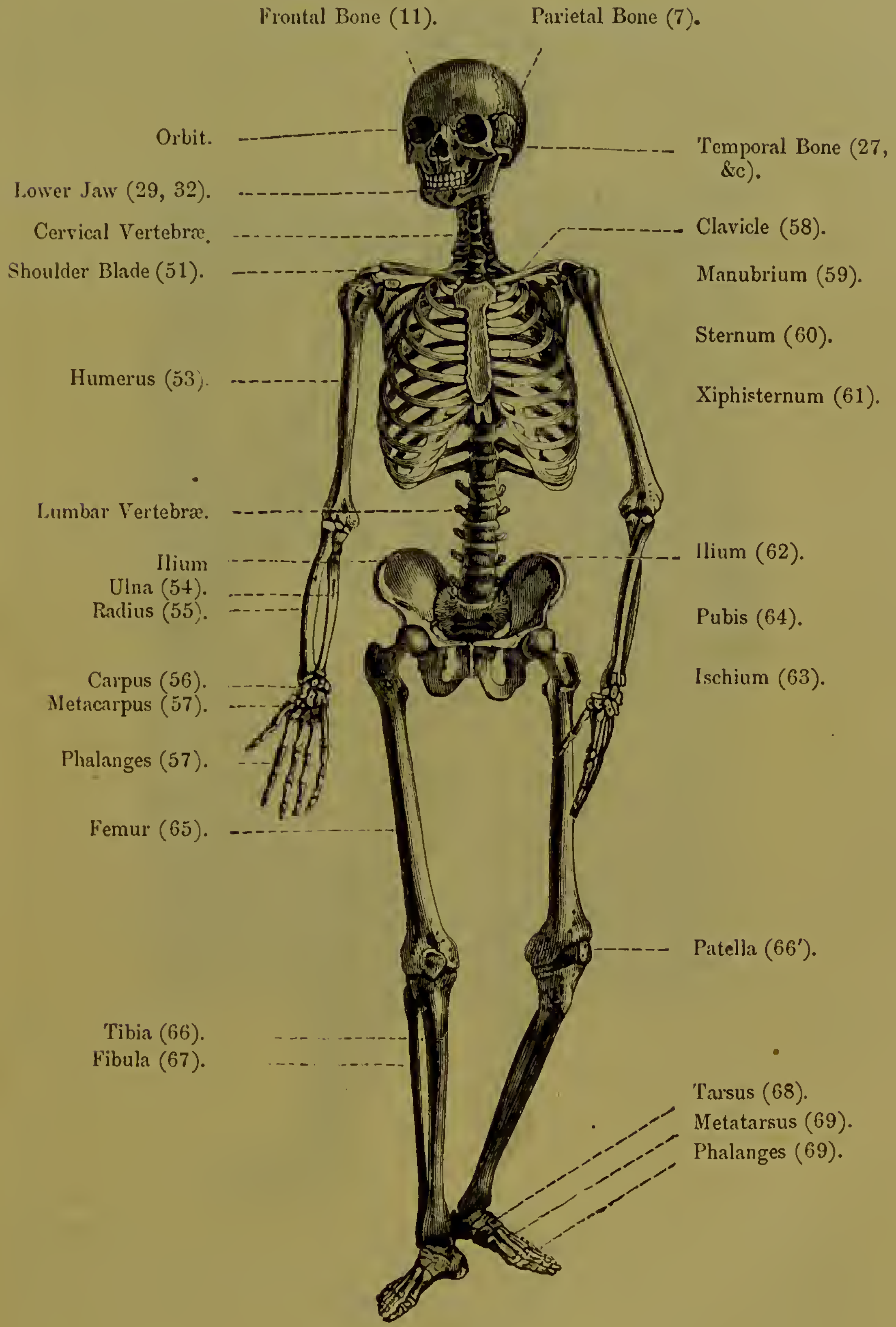
Viewing, then, the human body as a complicated whole, as a congeries of organs made up of various combinations of simple tissues, it may be observed, in reference to its external configuration, that it is rounded. This rounded form is principally owing to the large proportion of fluids which enter into its composition. The roundness of the face, limbs, and entire surface of the child, are in striking contrast to the unequal and irregular surface of the old man, whose humours are comparatively very much smaller in quantity.

The form of the human body is symmetrical, that is, it is capable of being divided into two lateral and corresponding halves. Suppose a median line to pass from the vertex of the head through the centre of the spinal column (Fig. 31); if the body be well formed, it will be divided by this line into two equal and corresponding portions. This symmetrical disposition of the body is not confined to its external configuration. It is true of many of the internal organs; but principally, as has been already stated, of those that belong to the animal life. The brain and the spinal cord are divisible into two equal halves (Fig. 32); the organs of sense are double and symmetrical: the muscles of one side of the body correspond to those of the other; the two hands and arms and the two lower extremities are alike; but for the most part, the organs of the organic life, the stomach, the intestines, the liver, the spleen, for example, are single, and not symmetrical.

The human body is divided into three great portions, the head, the trunk, and the extremities.

By the head is meant all that part of the body which is placed above the first bone of the neck. It is of a spheroidal figure, broader and deeper behind than before, somewhat like an egg in shape, with the broad end behind; it is flattened at its sides, and its peculiar figure renders it at once stronger and more capacious than it could have

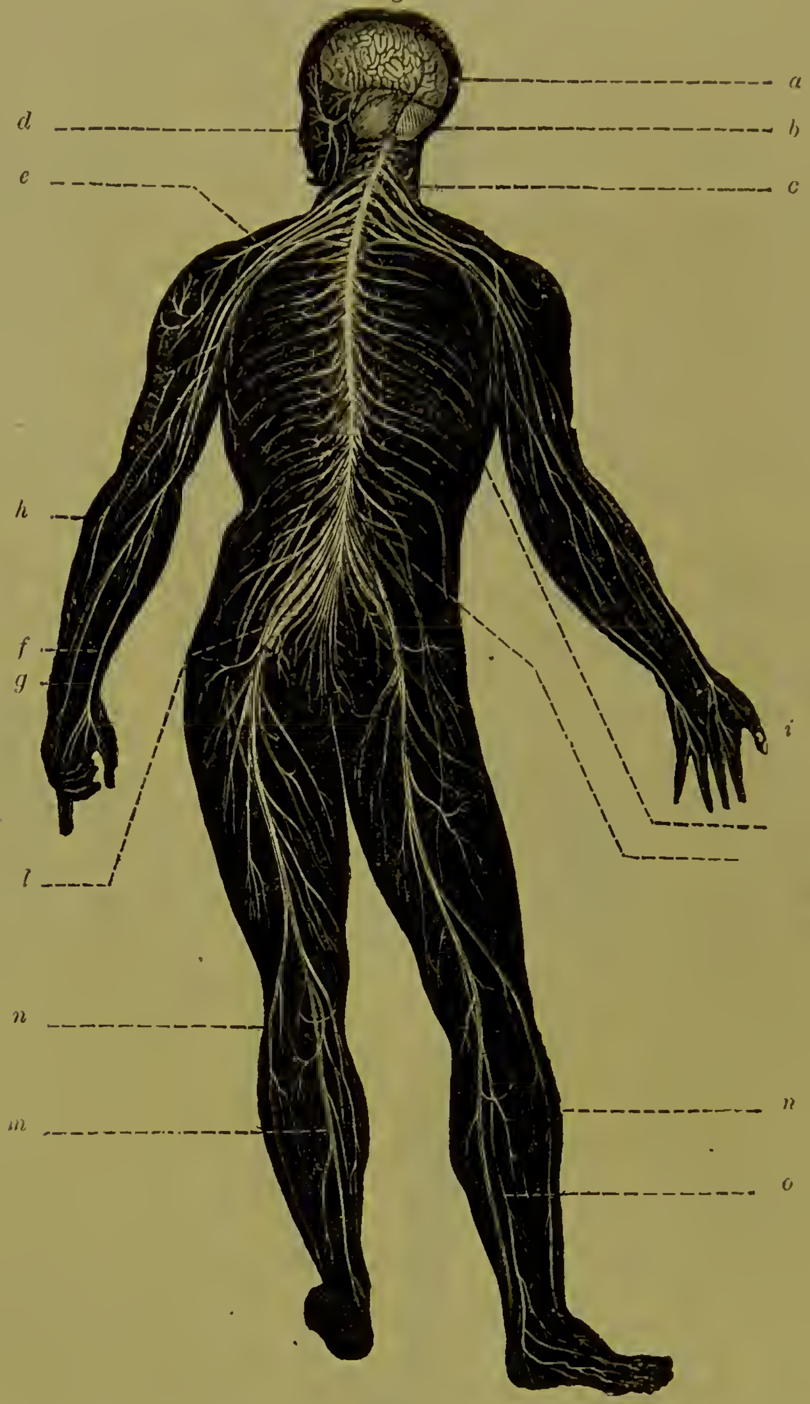
Fig. 31.



Human Skeleton.

been had it possessed any other form. It is supported by its base on the spinal column, to which it is attached by the peculiar structure termed a joint, and fastened by ligaments of exceeding strength.

Fig. 32.

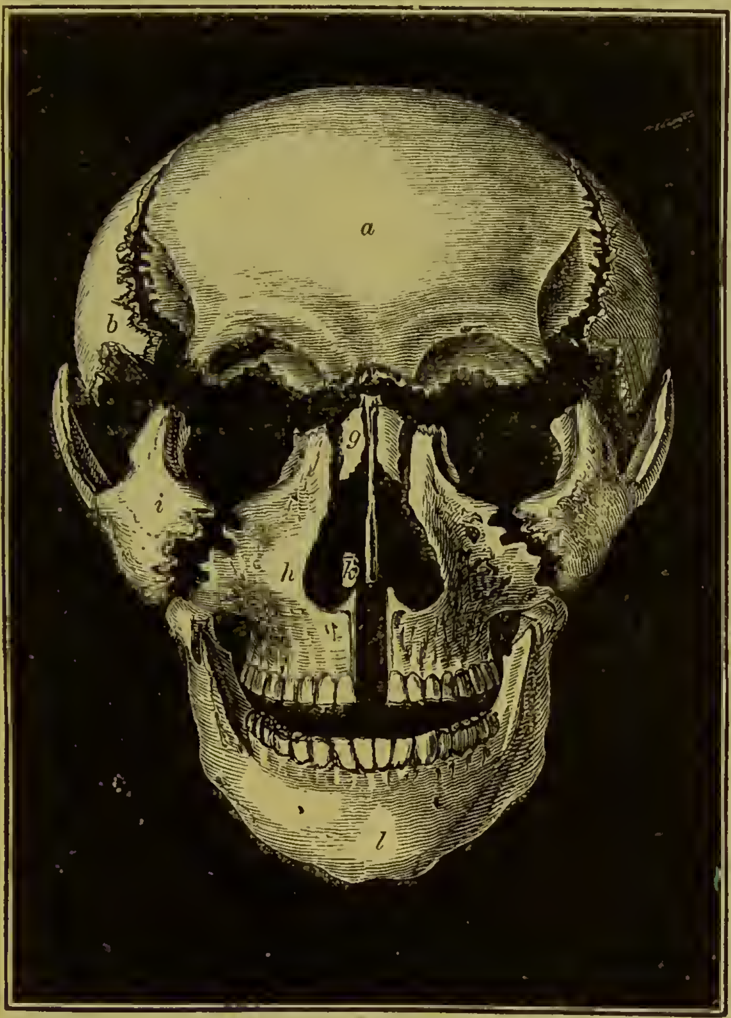


Nervous system in man, seen from behind. *a*, cerebrum; *b*, cerebellum; *c*, spinal marrow; *d*, facial nerve; *e*, brachial plexus caused by the union of several nerves coming from the spinal marrow; *f*, median nerve; *g*, cubital nerve; *h*, internal cutaneous nerve of the arm; *i*, radial and musculo-cutaneous nerve of the arm; *j*, intercostal nerves; *k*, femoral plexus; *l*, sciatic plexus; *m*, tibial nerve; *n*, external peroneal nerve; *o*, external saphenous nerve.

The head contains the central organ of the nervous system; the organs of the senses, with the exception of that of touch; and the organs of mastication. It comprehends the cranium and the face. It is composed partly of soft parts, as the teguments, namely, skin, fat, &c., and muscles; and partly of bones.

The bones of the cranium are eight in number, six of which are proper to the cranium, and two are common to it and to the face. The six bones proper to the cranium are the frontal (Figs. 33 and 34, *a*), the two parietal (Fig. 34, *b*), the two temporal (Fig. 34, *c*), and the occipital (Figs. 34 and 35, *d*); the two common to the cranium and face are the ethmoidal (Fig. 35, *f*), and the sphenoidal (Fig. 35, *e*). The frontal bone forms the entire fore part of the vault; the two parietal form the upper and middle part of it; the two temporal form the lower part of the sides; the occipital forms the whole hinder part, together with a portion of the base, while the ethmoidal forms the fore part, and the sphenoidal the middle part of the base.

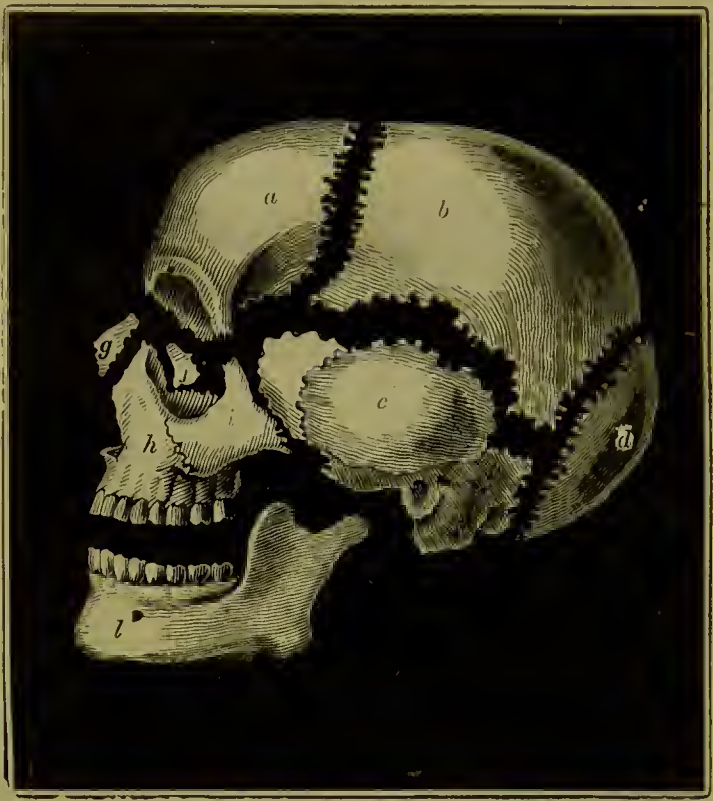
Fig. 33.



Bones of the skull, separated; front view. *a*, frontal bone; *b*, portions of the parietal bones; *i*, malar or cheek bones; *g*, nasal bones; *h*, superior maxillary or bones of the upper jaw; *k*, the vomer; *l*, the inferior maxillary or bone of the lower jaw.

These bones are firmly united together. The union of bones is technically called an *articulation* or *joint*. All joints are either immoveable or moveable. The union of the bones of the cranium affords an example of an immoveable articulation. Prominences and indentations, like the teeth of a saw, are formed in the margins of the contiguous bones (Fig. 36). At these inequalities of surface, which are exactly adapted to each other, the two bones are in immediate apposition in such a manner as to preclude the possibility of motion, and even to render the separation extremely difficult. This mode of articulation is termed a *suture*. There are certain advantages in constructing the cranium of several distinct bones, and in uniting them in this peculiar mode. 1. The walls of the vault are stronger then they could have been had they been formed of a single piece. 2. In the fœtus, the bones are at some distance from each other (Fig. 38); at birth, they yield and overlap one another; and in this manner they conduce to the security and ease of that event. 3. Minute vessels pass abundantly and securely through the interstices of the sutures to and from the interior of the cranium; in this manner, a free communication is established between the vessels within and without this

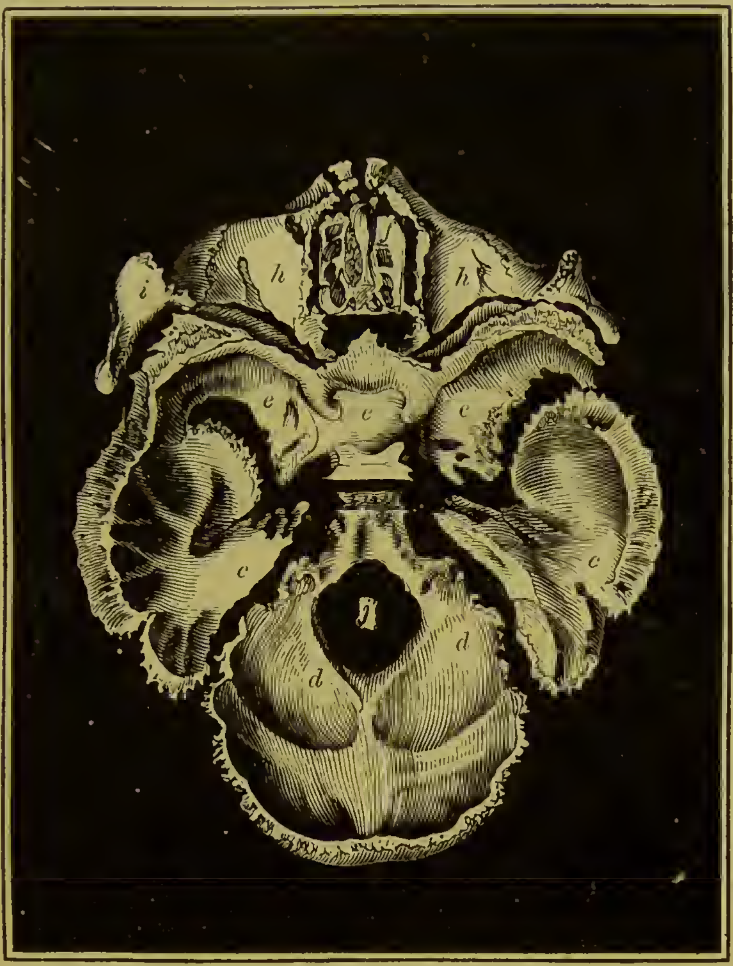
Fig. 34.



Bones of the skull, separated; side view. *a*, frontal bone; *b*, parietal bone; *d*, occipital bone; *c*, temporal bone; *g*, nasal bone; *i*, malar bone; *h*, superior maxillary bone; *j*, the unguis; *l*, the inferior maxillary bone.

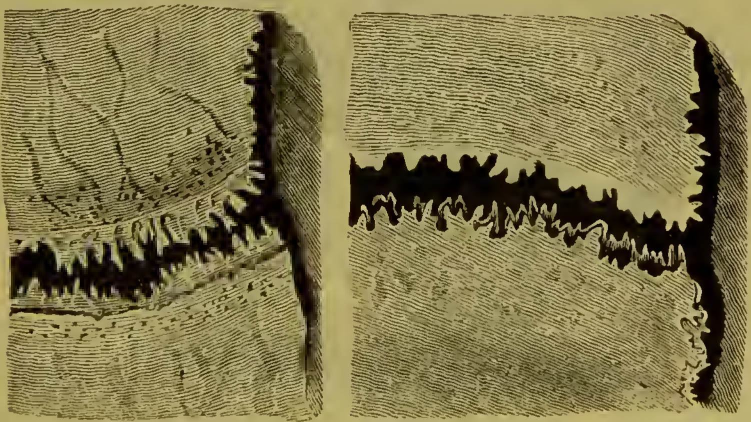
cavity. 4. It is probable that the shock produced by external

Fig. 35.



Bones forming the base of the skull; viewed from the inside. *d*, occipital bone; *c*, temporal bones; *e*, sphenoid bone; *f*, ethmoid bone; *h*, superior maxillary bones, or bones of the upper jaw; *i*, malar or cheek bones; *j*, foramen magnum.

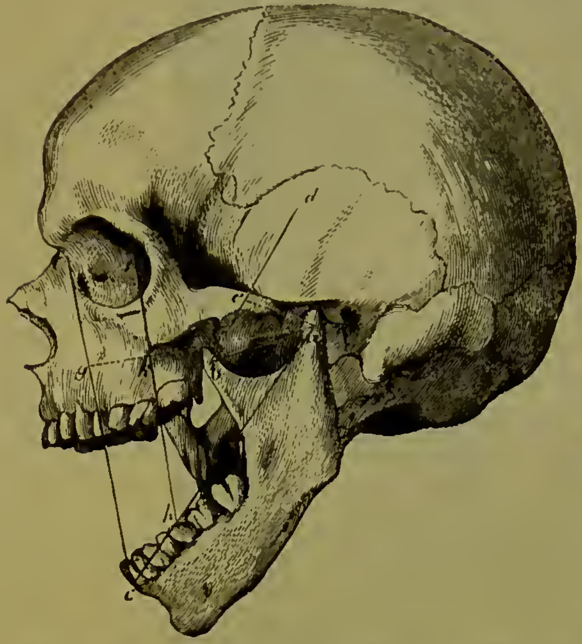
Fig. 36.



Portions of the bones of the cranium; showing the corresponding inequalities in their margins: which margins, when in apposition, constitute the mode of union termed suture. *a*, external surface of the bone; *b*, internal surface.

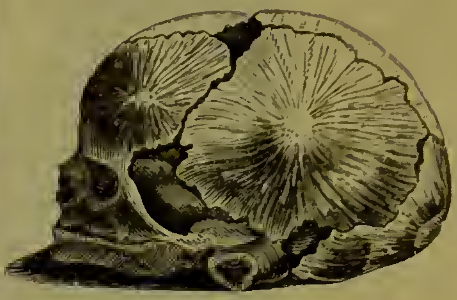
violence is diminished in consequence of the interruption of the vibration occasioned by the suture; it is certain that fracture is prevented by it from extending as far as it would do in one continued bony substance.

Fig. 37.



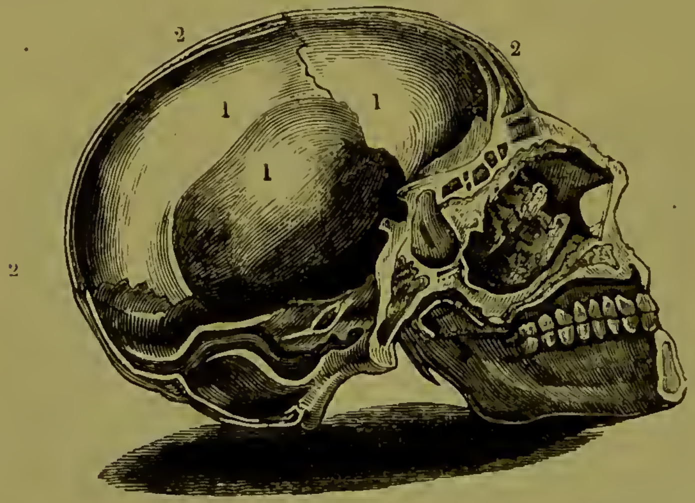
From Valentin. In the act of mastication the lower jaw, *a*, *i*, is pressed against the immovable upper one, *k*, *g*. Since the upper and lower rows of teeth are arranged symmetrically, it is only the corresponding masticatory surfaces of opposed teeth which work upon each other.

Fig. 38.



Side view of the fœtal skull, showing the bones imperfectly ossified, separated to some extent from each other, the interspace being occupied by membrane. The small size of the face compared with that of the cranium is strikingly apparent.

Fig. 39.



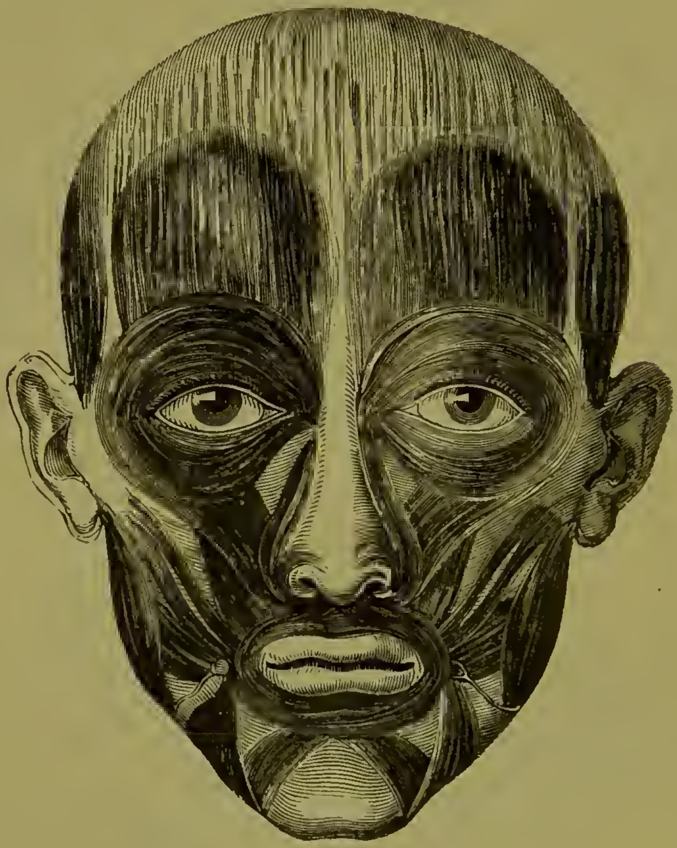
Section of the skull. 1, cavity of the cranium occupied by the brain; 2, cut edge of the bones of the cranium, showing the two tables of compact bone and the intervening spongy texture called diploë.

The vault of the cranium forms a cavity which contains the brain (Fig. 39). The size of this cavity is proportioned to that of the organ it lodges and protects. The form and magnitude of the cavity, and the shape and size of the cranium, depend upon the brain, and not those of the brain upon the cranium. The soft parts model and adapt to themselves the hard, the hard does not model and adapt the soft. The formation of the brain in the fœtus is anterior to that of the case which ultimately contains it; and the hard bone is moulded upon the soft pulp, not the pulp upon the bone. At every period of life, on the inner surface of the cranium there are visible impressions made by the convolutions of the brain, and the ramifications of the arteries, and on its external surface are depressions occasioned by the action of the external muscles. Nor does the modifying power of the brain over the bones of the cranium terminate at birth. The formation of bone, always a slow process, is never completed until the child has attained its third or fourth year, and often not until a much later period. At this tender age, the bones, which in advanced life are hard and rigid, are comparatively soft and yielding, and consequently more readily receive and retain the impression of the convolutions and of the other projecting parts of the brain, by which they are sometimes so deeply marked that an attentive examination of the inner surface of the cranium is of itself sufficient to determine not only that some part, but to indicate the very part of the brain which has been preternaturally active. At this tender age, pressure, internal or external, general or partial, may readily change the form of the cranium. If by a particular posture, the head of a child be unequally balanced on the spine, the brain will press more on that side of the cranium than on the other; the organ will expand in the direction to which it inclines; that portion of it will become preternaturally developed, and consequently the balance of its functions will be disturbed. An awkward way of standing or sitting, perhaps contracted inadvertently and kept up by habit; a wry neck; any cause that keeps the head constantly inclined to one side, may produce this result, examples of which, and of its consequences, will be given hereafter.

Tracing them from without inwards we see, then, that the various coverings afforded to the brain, the central organ of the animal life, seated in its vaulted cavity, are: 1. The tegument, consisting of the skin and of cellular and adipose membrane. 2. Beneath the tegument, muscles in the forepart and at the vertex, comparatively slender and delicate; at the sides and posteriorly, thick, strong, and powerful. 3. Beneath the muscles, a thin but dense membrane, termed the pericranium, lining the external surface of the cranial bones. 4. Beneath the pericranium, the bony substance of the cranium, consisting of two firm and hard bony plates, with a spongy, bony structure, called diploë, interposed between them (Fig. 39, 2). 5. Immediately in contact with the inner surface of the bony substance of the cranium, and forming its internal lining, the dense and strong membrane, called the *dura mater*, not only affording a general covering to the brain, but sending firm partitions between individual portions of it. 6. A serous membrane lining the internal surface of the dura mater, and reflected over the entire surface of the brain, termed the arachnoid tunic. 7. A thin and delicate membrane in immediate contact with the substance of the brain, descending between all its convolutions, called the pia mater. 8. An aqueous fluid, contained between the arachnoid membrane and the pia mater. Skin, muscle, pericranium, bone, dura mater, arachnoid membrane, pia mater, and aqueous fluid, superimposed one upon another, form, then, the covering and defence of the brain; so great is the care taken to protect this soft and tender substance.

The bones of the *face* consist of fourteen, namely, the two superior maxillary or jaw-bones (Fig. 33, *h*), the two malar or cheek bones (Fig. 33, *i*), the two nasal bones (Fig. 33, *g*), the two palate bones, the two ossa unguis (Fig. 34, *j*), the two inferior turbinated bones, the vomer (Fig. 33, *k*), and the inferior maxilla or the lower jaw (Fig. 33, *l*). This irregular pile of bones is divided into the superior and inferior maxilla or jaws; the superior maxilla being the upper

Fig. 40.



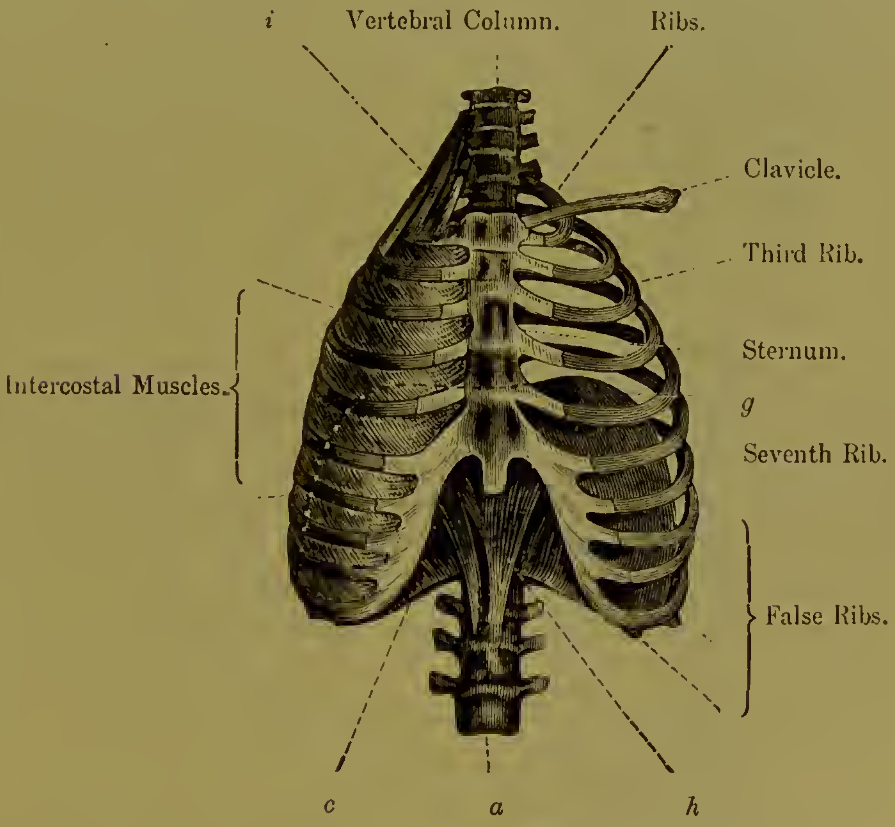
Muscles of the face.

and immoveable portion of the face; the inferior maxilla being the lower and moveable portion of it. Besides these bones, the face contains thirty-two teeth, sixteen in each jaw. The bones of the upper jaw are united together by sutures, and the union is so firm, that they have no motion but what they possess in common with the cranium. The lower jaw is united by a distinct articulation with the cranium (Fig. 37).

Besides the bones and the teguments, the face contains a number of muscles, which, for the most part, are small and delicate (Fig. 40), together with a considerable portion of adipose matter; while, as has been stated, the face and head together contain all the senses, with the exception of that of touch, which is diffused, more or less, over the entire surface of the body.

The second great division of the body, termed the TRUNK, extends from the first bone of the neck to that called the pubis in front, and to the lower end of the coccyx behind. It is subdivided into the thorax, the abdomen, and the pelvis.

Fig. 41.



Thorax of Man.

The *thorax* or *chest* extends above from the first rib, by which it is connected with the neck, to the diaphragm below, by which it is divided from the abdomen (Fig. 41). It consists partly of muscles and partly of bones: the muscular and the osseous portions being in nearly equal proportions. Both together form the walls of a cavity in which are placed the central organs of circulation and respiration. The chief boundaries of the cavity of the thorax before, behind, and at the sides, are osseous (Fig. 41); being formed before, by the sternum or breast-bone (Fig. 31); behind, by the spinal column or back bone; and at the sides, by the ribs. Below, the boundary is muscular, being formed by the diaphragm (Fig. 41, *c*, *g*, *h*), while above the thorax is so much contracted, that there is merely a space left for the passage of certain parts which will be noticed immediately.

The figure of the thorax is that of a cone, the apex being above (Fig. 41), through the aperture of which pass the tubes that lead to the lungs and stomach, and the great blood-vessels that go to and from the heart (Fig. 47). The base of the cone is slanting, so that the thorax is considerably shorter before than behind, like an oblique section of the cone.

The osseous portion of the walls of the thorax is formed behind by the spinal column, a range of bones common indeed to all the divisions of the trunk; for it constitutes alike the posterior boundary of the thorax, abdomen, and pelvis (Fig. 42). The spinal column is composed of thirty distinct bones, twenty-four of which are separate and moveable on one another, and on this account are called true vertebræ (Fig. 43, 2, 4); the other five, though separate at an early period of life, are subsequently united into a single solid piece, called the sacrum (Fig. 31). The bones composing this solid piece, as they admit of no motion on each other, are called false vertebræ. To the extremity of the sacrum is attached the last bone of the series, termed the coccyx (Fig. 42.)

From above downwards, that is, from the first bone of the neck to the first bone of the sacrum, the separate bones forming the column progressively increase in size; for this column is the chief support of the weight of the head and trunk, and this weight is progressively augmenting to this point. From the sacrum to the coccyx, the bones successively diminish in size, until, at the extremity of the coccyx, they come to a point. The spinal column may, therefore, be said to consist of two pyramids united at their base. The superior pyramid is equal in length to about one-third of the height of the body, and it is this portion of the column only that is moveable.

The two surfaces of the spinal column, the anterior and the posterior, present a striking contrast. The anterior surface, which in its whole extent is rounded and smooth, is broad in the region of the neck, narrow in the regions of the back, and again broad in the region of the loins. It presents three curvatures (Fig. 42); the convexity of that of the neck being forwards, that of the back backwards, and that of the loins again forwards.

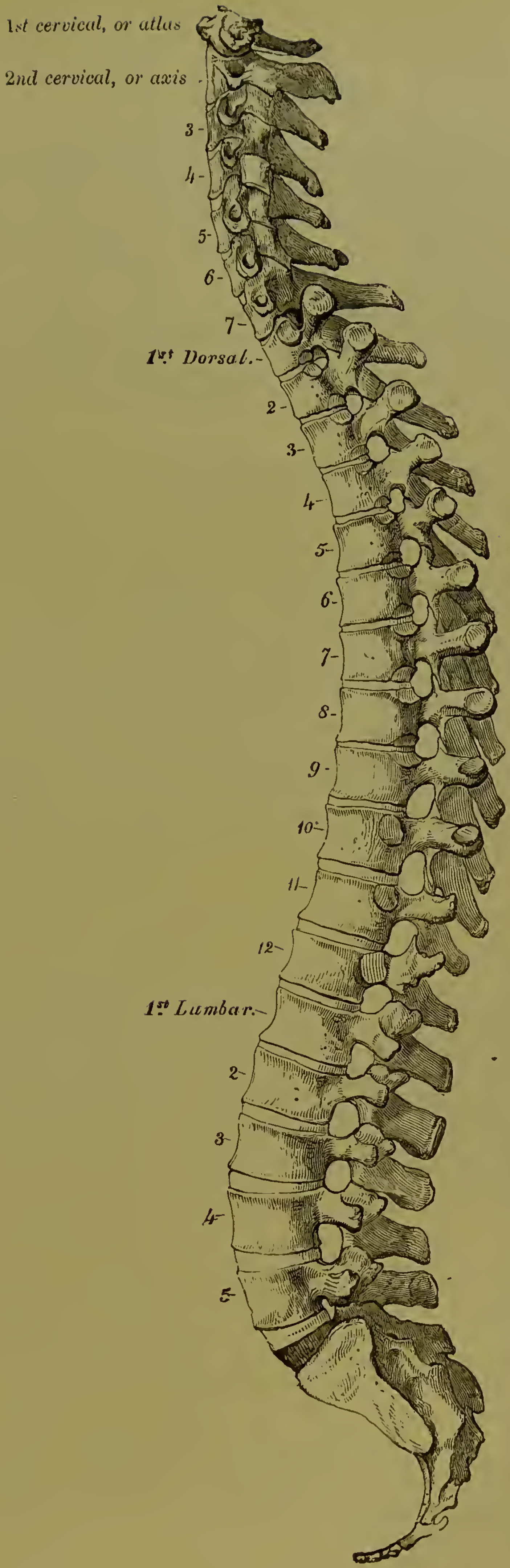


Fig. 42.—Lateral View of the Spine.

To face page 80.

From the posterior surface of the column, which is everywhere irregular and rough, spring, along the medium line, in regular series, strong, sharp, and pointed projections of bone (Fig. 42), which from being sharp and pointed, like elongated spines, are called spinous processes, and have given name to the whole chain of bones. These processes afford fixed points for the action of powerful muscles. Extending the whole length of the column, from the base of the skull to the sacrum, on each side of the spinous processes, are deep excavations, which are filled up with the powerful muscles that maintain the trunk of the body erect.

From the lateral surfaces of the column likewise spring short but strong projections of bone, termed transverse processes, which also give attachment to powerful muscles (Fig. 42).

The separate bones of the series have a kind of turning motion on each other; hence each is called a vertebra, and the name of vertebral column is often given to the entire series, as well as that of spinal column. That portion of the column which forms the neck consists of seven distinct bones, called cervical vertebræ (Fig. 43, 2); that portion which forms the back consists of twelve, called dorsal vertebræ (Fig. 43, 3); that portion which forms the loins consists of five, called lumbar vertebræ (Fig. 43, 4). Between each of these classes of vertebræ there are specific differences, but they need not be described here: all that is necessary to the present purpose is an account of the structure which is common to every vertebra.

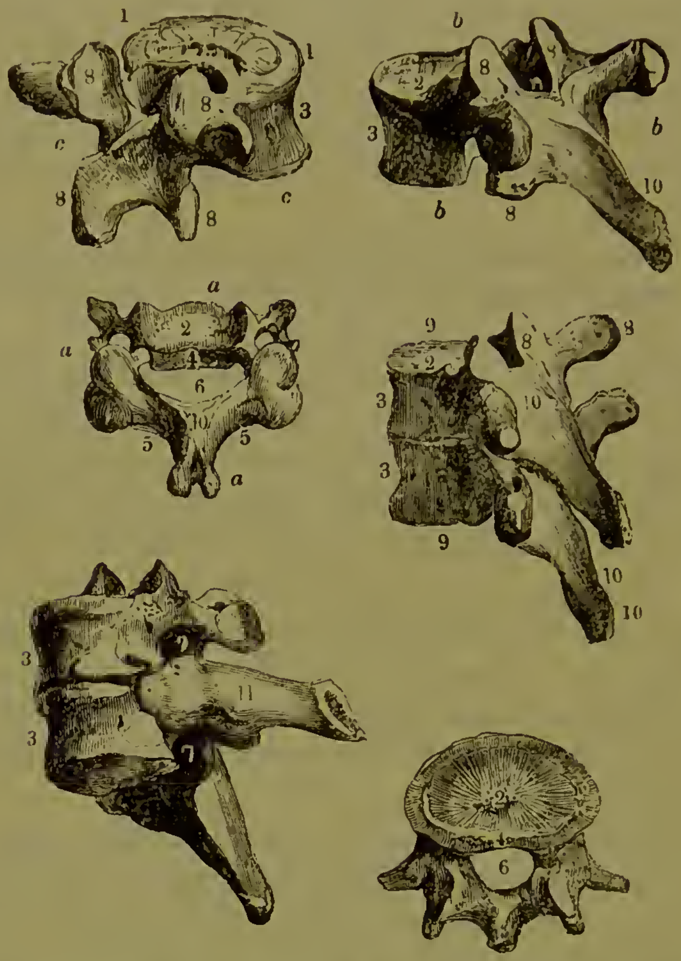
By inspecting Fig. 43, it will be seen that the upper and under edges of each vertebra consist of a ring of bone, of a firm and compact texture, rendering what may be called the body of the vertebra exceedingly strong. This ring of bone forms a superficial depression (Fig. 43, 2), for the reception of a peculiar substance, immediately to be described, which is interposed between each vertebra (Fig. 44).

The anterior surface of the body of the vertebra is convex; its posterior surface is concave; from the posterior surface springs a bony arch (Fig. 43, 5), which, together with the posterior concavity, forms an aperture of considerable magnitude, a portion of the canal for the passage of the spinal cord.

Both the upper and under edges of the arch form a notch (Fig. 43, 7), which, together with a corresponding notch in the contiguous vertebra, completes another aperture rounder and smaller than the former, but still of considerable size, the passage of the spinal nerves.

From both the upper and under sides of the arch proceeds a short but strong projection of bone (Fig. 43, 8), termed the articulating processes, because it is chiefly by these processes that the vertebræ are connected together. From the beginning to the end of the series, the two upper processes of the one vertebra are united with the two lower processes of the vertebra immediately above it (Fig. 43, 9), and around the edges of all the articulating processes are visible rough lines, which mark the places to which the articulating ligaments are attached.

Fig. 43.

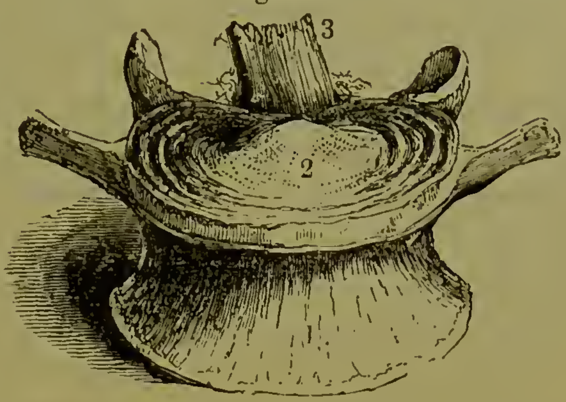


View of some of the vertebræ, which by their union form the spinal column.
a, A vertebra of the neck; *b*, a vertebra of the back; *c*, a vertebra of the loins.
1, Ring of compact bone forming, 3, the body of the vertebra; 2, superficial depression for the reception of the intervertebral cartilage; 3, anterior surface of the body of the vertebra; 4, posterior surface; 5, bony arch; 6, opening for the passage of the spinal cord; 7, opening for the passage of the spinal nerves; 8, articulating processes by which the vertebræ are joined to each other; 9, two dorsal vertebræ united, showing the arrangement of, 10, the spinous processes; 11, a portion of a rib articulated with the side of the vertebra.

No vertebra, except the first, rest immediately upon its contiguous vertebra (Fig. 42). Each is separated from its fellow by a substance of a peculiar nature interposed between them, termed the intervertebral substance (Fig. 44). This substance partakes partly of the nature of cartilage, and partly of that of ligament. It is composed of concentric plates, formed of oblique fibres, which intersect each other in every direction. This substance, for about a quarter of an inch from its circumference towards its centre, is tough, strong, and unyielding; then it becomes softer, and is manifestly elastic; and so it continues until it approaches the centre, when it becomes pulpy, and is again inelastic.

The exterior tough and unyielding matter is for the firmness of the connexion of the several vertebræ with each other; the interior softer and elastic matter is for the easy play of the vertebræ upon each other; the one for security, the other for pliancy. And the adjustment of the one to the other is such as to combine these properties in a perfect manner. The quantity of the unyielding substance is not so great as to produce rigidity; the quantity of the elastic substance is not so great as to occasion insecurity. The firm union of its solid matter renders the entire column strong; the aggregate elasticity of its softer substance renders it springy.

Fig. 44.



1. One of the lumbar vertebræ. 2. Intervertebral substance. 3. A portion of the spinal cord in its canal.

The column is not constructed in such a manner as to admit of an equal degree of motion in every part of it. Everything is contrived to give to that portion which belongs to the neck freedom of motion, and, on the contrary, to render that portion which belongs to the back comparatively fixed. In the neck the mechanism of the articulating processes is such as to admit of an equal degree of sliding motion forwards, backwards, and from side to side, together with a turning motion of one bone upon another; at the same time, the intervertebral substance between the several vertebræ is thick. In consequence of this mechanism, we can touch the breast with the chin, the back with the hind head, and the shoulders with the ear, while we can make the head describe more than a semicircle. But, in the back, the articulating processes are so connected as to prevent the possibility of any motion, either forwards or backwards, or any turning of one vertebra upon another, while the intervertebral substance is comparatively thin. That portion of the column which belongs to the back is intended to afford a fixed support for the ribs, a support which is indispensable to their action in the function of respiration. In the loins, the articulating processes are so connected as to admit of a considerable degree of motion in the horizontal direction, and from side to side, and the intervertebral substance here progressively increases in thickness to the point at which the upper portion of the column is united to the sacrum, where the degree of motion is extensive.

The canal for the spinal cord, formed partly by the concavity in the posterior surface of the vertebra, and partly by the arch that springs from it (Fig. 43, 6), is lined by a continuation of the dense and strong membrane that constitutes the internal periosteum of the cranium, the dura mater, which, passing out of the opening in the occipital bone called the foramen magnum (Fig. 35, *j*), affords a smooth covering to the canal throughout its whole extent.

The spinal cord itself, continuous with the substance of the brain, passes also out of the cranium through the foramen magnum into the spinal canal, enveloped in the delicate membranes that cover it, and surrounded by the aqueous fluid contained between those membranes. The size of the spinal canal, adapted to that of the spinal cord, which it lodges and protects, is of considerable magnitude, and of a triangular shape in its cervical portion, smaller and rounded in its dorsal portion, and again large and triangular in its lumbar portion.

The spinal column performs several different, and apparently incompatible, offices.

First, it affords a support and buttress to other bones. It sustains the head (Fig. 31); it is a buttress to the ribs: through the sternum and ribs it is also a buttress to the superior, and through the pelvis, to the lower, extremities.

Secondly, it affords a support to powerful muscles, partly to those that maintain the trunk of the body in the erect posture against the force of gravitation, and partly to those that act upon the superior and inferior extremities in the varied, energetic, and sometimes long-continued movements they execute.

Thirdly, it forms one of the boundaries of the great cavities that contain the chief organs of the organic life. To the support and protection of those organs it is specially adapted; hence the surface in immediate contact with them is even and smooth; hence its different curvatures, convexities, and concavities, have all reference to their accommodation; hence in the neck it is convex (Fig. 42), in order to afford a firm support to the œsophagus, the windpipe, the aorta, and the great trunks of the venous system: in the back it is concave, in order to enlarge the space for the dilatation of the lung. in the act of inspiration; in the loins it is convex, in order to sustain and fix the loose and floating viscera of the abdomen; in the pelvis it is concave, in order to enlarge the space for lodging the numerous delicate and highly-important organs contained in that cavity.

Fourthly, it forms the osseous walls of a canal for the lodgment and protection of the soft and tender substance of the spinal cord, one of the great central masses of the nervous system, the seat of the animal life.

Fifthly, it affords in its osseous walls secure apertures for the passage of the spinal nerves (Fig. 32), by which impressions are transmitted from the organs to the spinal cord and brain, in the function of sensation; and from the spinal cord and brain to the organs in the function of volition.

For the due performance of these offices, it is indispensable that it should be firm, rigid, strong, and yet to a certain extent readily flexible in every direction. By what mechanism is it endowed with these apparently incompatible properties?

By means of the ring of compact bone, which forms so large a part of its body (Fig. 43, 1), it is rendered firm, rigid, and strong. By means of its numerous separate pieces, exactly adjusted to each other, and dove-tailed into one another, an increase of strength is gained, such as it would not have been possible to communicate to a single solid piece. By the same mechanism, some degree of flexibility is also obtained; each separate bone yielding to some extent, which, though slight in a single bone, becomes considerable in the twenty-four.

But the flexibility required is much greater than could be obtained by this expedient alone. A rigid and immoveable pile of bones, in the position of the spinal column, on which all the other parts of the body rest, and to which they are directly or indirectly attached, would necessarily have rendered all its movements stiff and mechanical; and every movement of every kind impossible but in a given direction. That the movements of the body may be easy, free, and varied; that it may be possible to bring into play new and complex combinations of motion at any instant, with the rapidity of the changes of thought at the command of the impulses of feeling, it is indispensable that the spinal column be flexible in every direction, forwards, backwards, and at the sides: it is equally indispensable that it be thus capable of yielding, without injuring the spinal cord, without injuring the spinal nerves, without injuring the thoracic and abdominal viscera, and without injuring the muscles of the trunk and extremities. The degree in which it possesses this power of flexibility, and the extent to which, by the cultivation of it, it is sometimes actually brought, is exemplified in the positions and contortions of the posture-master and the tumbler. It is acquired by means of the intervertebral substance, the compressible and elastic matter interposed between the several vertebræ. So compressible is this substance, that the human body is half an inch shorter in the evening than in the morning, having lost by the exertions of the day so much of its stature; yet so elastic is this matter that the stature lost during the day is regained by the repose of the night. The weight of the body pressing in all directions upon the spinal column; muscles, bones, cartilages, ligaments, membranes, with all their vessels and all the fluids contained in them; the weight of all these component parts of the head, trunk, and extremities, pressing, without the cessation of an instant, during all the hours of vigilance, upon the intervertebral substance, compresses it; but this weight, being taken off during the night, by the recumbent posture of the body, the intervertebral substance, in consequence of its elasticity, regains its original bulk, and of course the spinal column its original length.

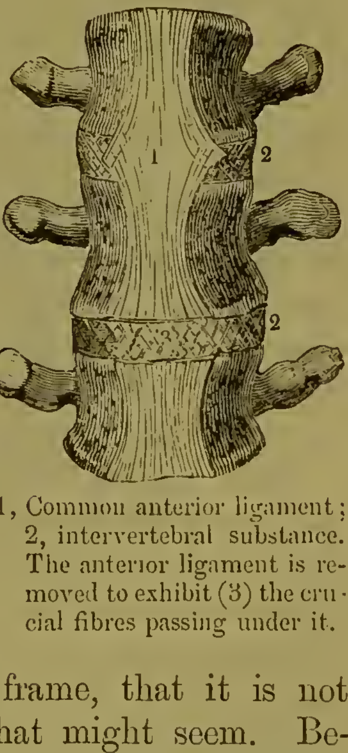
But the flexibility acquired through the combined properties of compressibility and elasticity, is exceedingly increased by the action of the pulpy and inelastic matter in the centre of the intervertebral substance; this matter serving as a pivot to the vertebræ, facilitating their motion on each other. Its effect has been compared to that of a bladder partly filled with water, placed between two trenchers: in this case, the approximation of the circumference of the two trenchers on one side, would instantly displace a portion of the water on that side, which would occupy the increasing space on the other, with the effect of facilitating the change, in every possible direction, of the position of the two trenchers in relation to each other. To this effect, however, it is indispensable that the matter immediately around this central pivot should be, not like itself, rigid and unyielding, but compressible and elastic. It is an interesting fact, that since this illustration was suggested, it has been discovered that this very arrangement is actually adopted in the animal body. In certain animals, in the very centre of their intervertebral substance, there has been actually found a bag of water, with a substance immediately surrounding the bag, so exceedingly elastic, that when the bag is cut, the fluid contained in it is projected to the height of several feet in a perpendicular stream.

But besides securing freedom and extent of motion, the intervertebral substance serves still another purpose, which well deserves attention.

Firmness and strength are indispensable to the fundamental offices performed by the column; and to endow it with these properties, we have seen that the external concentric layers of the intervertebral substance are exceedingly tough, and that they are attached to the bodies of the vertebræ, which are composed of dense bone. But bone is well calculated to receive and transmit a shock or jar on the application of any degree of force to the column. Yet such force must necessarily be applied to it in every direction, from many points of the body during almost every moment of the day; and did it actually produce a corresponding shock, the consequence would be fatal: the spinal cord and brain would be inevitably killed; for the death of these tender and delicate substances may be produced by a violent jar, although not a particle of the substances themselves be touched. A blow on the head may destroy life instantaneously, by what is termed concussion; that is, by the communication of a shock to the brain through the bones of the cranium. The brain is killed; but on careful examination of the cerebral substance after death, not the slightest morbid appearance can be detected; death is occasioned merely by the jar. A special provision is made against this evil, in the structure of the bones of the cranium, by the interposition between its two compact plates of the spongy substance called diploë, and this is sufficient to prevent mischief in ordinary cases. A great degree of violence applied directly to the head is not common: thousands of people pass through life without ever having suffered from it on a single occasion: but every hour, in the ordinary movements of the body, and much more in the violent movements which it occasionally makes, a degree of force is applied to the spinal column, and through it transmitted to the head, such as, did it produce a proportionate shock, would inevitably and instantly destroy both spinal cord and brain. The evil is obviated partly by the elastic, and partly by the non-elastic properties of the matter interposed between the several layers of compact bone. By means of the elastic property of this matter, the head rides upon the summit of the column as upon a pliant spring, while the canal of the spinal cord remains secure and uninvaded. By means of the soft and pulpy portion of this matter, the vibrations excited in the compact bone are absorbed, point by point, as they are produced: as many layers of this soft and pulpy substance, so many points of absorption of the tremors excited in the compact bone; so many barriers against the possibility of the transmission of a shock to the delicate nervous substance.

Alike admirable is the mechanism by which the separate pieces of the column are joined together. If but one of the bones were to slip off its corresponding bone, or to be displaced in any degree, incurable paralysis, followed ultimately by death, or instantaneous death, would happen; for pressure on the spinal cord in a certain part of its course is incompatible with the power of voluntary motion, and with the continuance of life for any protracted term; and in another part of its course, with the maintenance of life beyond a few moments. To prevent such consequences, so great is the strength, so perfect the attachment, so unconquerable the resistance, of that portion of the intervertebral substance which surrounds the edge of the bodies of the vertebræ, that it will allow the bone itself to give way rather than yield. Yet such is the importance of security to this portion of the frame, that it is not trusted to one expedient alone, adequate as that might seem. Besides the intervertebral substance, there is another distinct provision for the articulation of the bodies of the vertebræ. Commencing at

Fig. 45.



1, Common anterior ligament; 2, intervertebral substance. The anterior ligament is removed to exhibit (3) the crucial fibres passing under it.

the second cervical vertebra, in its fore part, and extending the whole length of the column to the sacrum, is a powerful ligament, composed of numerous distinct longitudinal fibres (Fig. 45), which are particularly expanded over the intervals between the bones occupied by the intervertebral substance. This ligament is termed the *common anterior vertebral.*

Corresponding with the ligament on the anterior, is another on the posterior part of the spine, which takes its origin from the foramen magnum; descends from thence, within the vertebral canal, on the posterior surface of the bodies of the vertebræ, and extends to the sacrum. This ligament is termed the *common posterior vertebral*, which, besides adding to the strength of the union of the bodies of the vertebræ, prevents the column itself from being bent too much forward.

Moreover, the bony arches of the vertebræ are connected by means of a substance partly ligamentous, and partly cartilaginous, which, while it is extremely elastic, is capable of resisting an extraordinary degree of force.

And in the last place, the articular processes form so many distinct joints, each being furnished with all the apparatus of a moveable joint, and thus possessing the ordinary provision for the articulation of bones, in addition to the whole of the foregoing securities.

"In the most extensive motion of which the spinal column is capable, that of flexion, the common anterior ligament is relaxed; the fore part of the intervertebral substance is compressed, and its back part stretched; while the common posterior ligament is in a state of extension. In the *extension* of the column the state of the ligaments is reversed; those which were extended being in their turn relaxed, while the common anterior vertebral is now put upon the stretch. In the *lateral inclination* of the column, the intervertebral substance is compressed on that side to which the body is bent. In the *rotary* motion of the column, which is very limited in all the vertebræ, but more particularly in the dorsal, in consequence of their attachment to the ribs, the intervertebral substance is contorted, as are likewise all the ligaments. All the motions of the column are capable of being aided to a great extent by the motion of the pelvis upon the thighs."

"The number and breadth of the attachments of these bones," says an accomplished anatomist and surgeon,* "their firm union by ligament, the strength of their muscles, the very inconsiderable degree of motion which exists between any two of them, and, lastly, the obliquity of their articular processes, especially in the dorsal and lumbar vertebræ, render dislocation of them, at least in those regions, impossible without fracture; and I much doubt whether dislocation even of the cervical vertebræ ever occurs without fracture, either through their bodies or their articular processes. The effects of each of these accidents would produce precisely the same injury to the spinal marrow, and symptoms of greater or less importance, according to the part of the spinal column that is injured. Death is the immediate consequence if the injury be above the third cervical vertebra, the necessary paralysis of the parts to which the phrenic and intercostal nerves are distributed, causing respiration instantly to cease. If the injury be sustained below the fourth cervical vertebra, the diaphragm is still capable of action, and dissolution is protracted. The symptoms, in fact, are less violent in proportion as the injury to the spinal marrow is further removed from the brain; but death is the inevitable consequence, and that in every case at no very distant period."

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* "Treatise on Ligaments." By Bransby B. Cooper, Esq.

So the object of the construction of the spinal column being to combine extent and freedom of motion with strength, and it being necessary to the accomplishment of this object to build up the column of separate pieces of bone, the connecting substances by which the different bones are united are constituted and disposed in such a manner as to prove absolutely stronger than the bones themselves. Such is the structure of this important portion of the human body, considered as a piece of mere mechanism; but our conception of its beauty and perfection would be most inadequate if we did not bear in mind, that while the spinal column performs offices so varied and apparently so incompatible, it forms an integrant portion of a living machine: it is itself alive: every instant blood-vessels, absorbents, and nerves, are nourishing, removing, renewing, and animating every part and particle of it.

The anterior boundary of the thorax is formed by the bone called the sternum, or the breast bone, which is broad and thick at its upper and thin and elongated at its lower extremity (Fig. 41), where it gives attachment to a cartilaginous appendix, which being pointed and somewhat like a broadsword, is called the ensiform cartilage.

Its position is oblique, being near the vertebral column at the top, and distant from it at the bottom. Its margins are thick, and marked by seven depressions, for the reception of the cartilages of the seven true ribs. Its anterior surface is immediately subjacent to the skin, and gives attachment to powerful muscles, which act on the superior extremities: its posterior surface is slightly hollowed, in order to enlarge the cavity of the thorax.

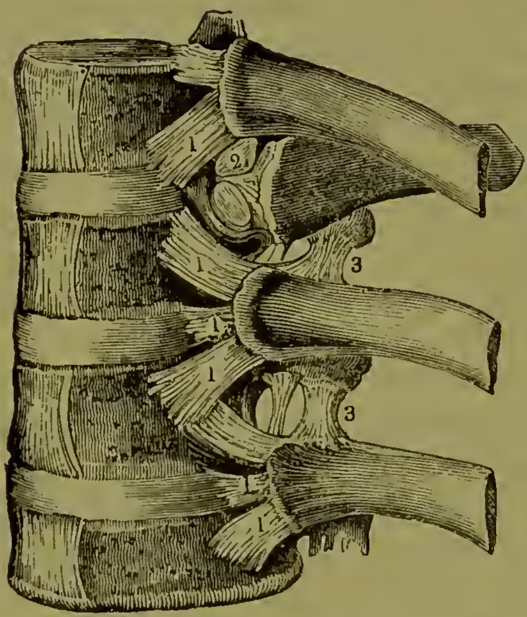
The thorax is bounded at the sides by the ribs, which extend like so many arches between the spinal column and the sternum (Figs. 41, 49). They are in number twenty-four, twelve on each side, of which the seven upper are united to the sternum by cartilage, and are called true ribs; the cartilages of the remaining five are united with each other, and are not attached to the sternum; these are called false ribs: all of them are connected behind to the spinal column (Fig. 49).

The ribs successively and considerably increase in length as far as the seventh, by which the cavity they encompass is enlarged; from the seventh they successively diminish in length, and the capacity of the corresponding part of the cavity is lessened. The direction of the ribs from above downwards is oblique. Their external or anterior surface is convex; their internal or posterior surface is concave: by the first, their strength is increased; by the second, the general cavity of the thorax is enlarged. Their upper margin is smooth and rounded, and gives attachment to a double layer of muscles, called the intercostal, placed in the intervals that separate the ribs from each other (Fig. 41). Along the lower margin is excavated a deep groove, for the lodgment and protection of the intercostal vessels.

The ribs are connected with the spinal column chiefly by what is termed the *anterior ligament* (Fig. 46), which is attached to the head of the rib (Fig 46), and which, dividing into three portions, firmly unites every rib to two of the vertebræ, and to the intervertebral substance. This articulation is fortified by a second ligament (Fig. 46, 2), also attached to a head of the rib, termed the *interarticular*, and by three others, one of which is attached on the fore part, and the two others in the back part, to the neck of the rib.

The cartilages of the seven superior ribs are attached to the sternum by a double layer of ligamentous fibres, termed the *anterior and the posterior ligaments of the sternum.* So strong are the bands which thus attach the ribs to the spinal column and the sternum, that the ribs cannot be dislocated without fracture. "Such at least is the case in experiments upon the dead body, where, though the rib be subjected to the application of force by means of an instrument best calculated to detach its head from the articulation, yet it is always broken."

Fig. 46.



Ligaments connecting the ribs to the spinal column. 1, anterior ligaments; 2, interarticular ligament; 3, ligaments of the necks of the ribs.

While thus firmly attached to their points of support, the ligaments which fix them are so disposed as to render the ribs capable of being readily moved upwards and downwards: upwards in inspiration, downwards in expiration;

and it is by this alternate action that they enlarge and diminish the cavity of the thorax in the function of respiration.

Such are the boundaries of the cavity of the thorax as far as its walls are solid. The interspaces between these solid portions at the sides are filled up by muscles, principally by those termed the intercostal (Fig. 41); below, the boundary is formed by the diaphragm (Fig. 49); while above, as has been already stated, the cavity is so contracted as only to leave an opening for the passage of certain parts to and from the chest.

The inner surface of the walls of the thorax, in its whole extent, is lined by a serous membrane, exceedingly thin and delicate, but still firm, called the pleura. The same membrane is reflected over the organs of respiration contained in the cavity, so as to give them an external coat. The membrane itself is everywhere continuous, and everywhere the same, whether it line the containing or the contained parts; but it receives a different name as it covers the one or the other: that portion of it which lines the walls of the cavity being called the costal pleura, while that which covers the organs contained in the cavity is termed the pulmonary pleura.

A fold of each pleura passes directly across the central part of the cavity of the thorax; extending from the spinal column to the sternum, and dividing the general cavity into two. This portion of the pleura is called the mediastinum, from its situation in the centre of the thorax, and it so completely divides the thoracic cavity into two, that the organs on one side of the chest have no communication with those of the other; so that there may be extensive disease in one cavity (for example, a large accumulation of water), while the other may be perfectly sound.

The main organs contained in the cavity of the thorax are the lungs with their air tube; the heart with its great vessels; and the tube passing from the mouth to the stomach (Fig. 47).

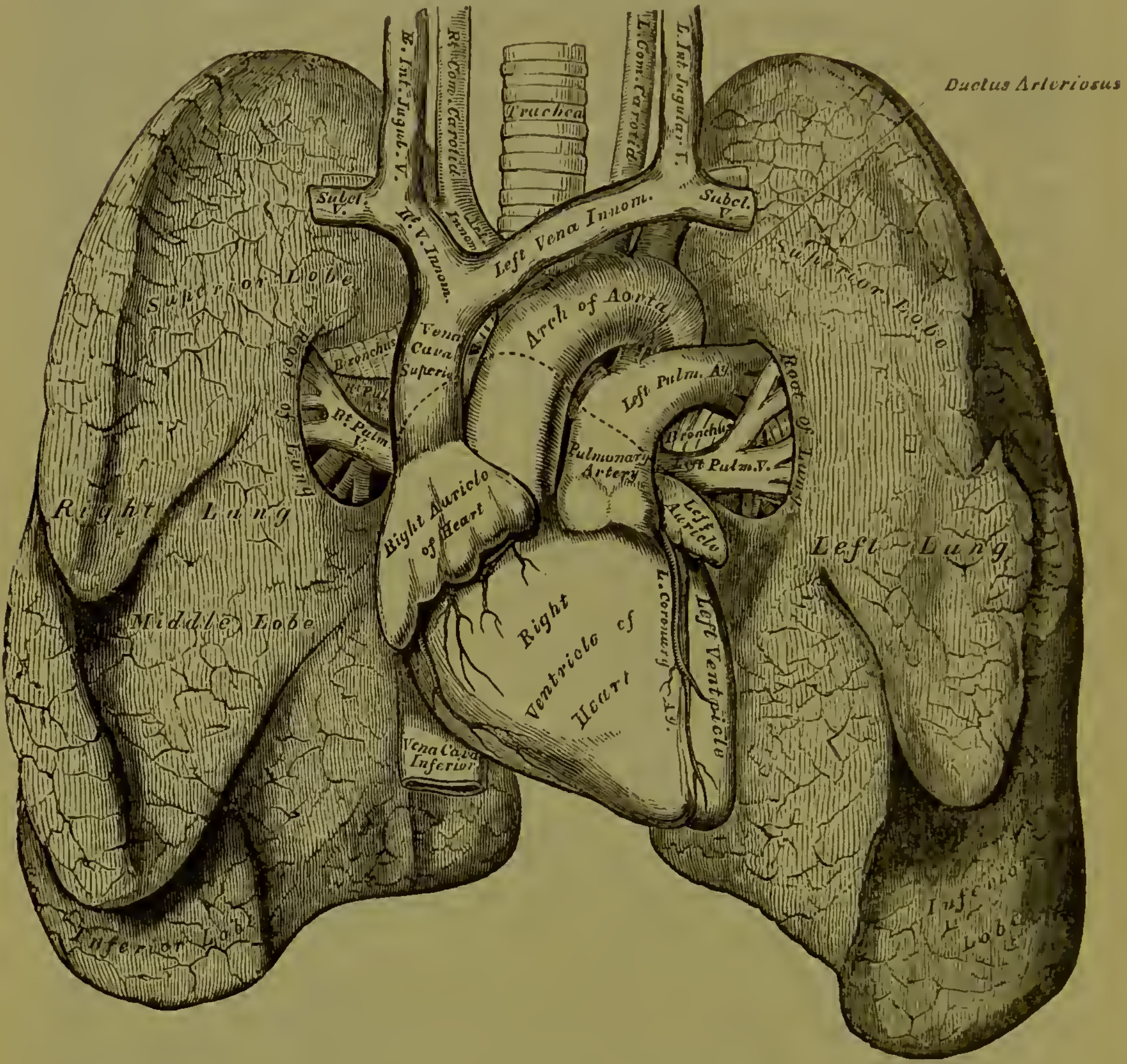
The two lungs occupy the sides of the chest (Fig. 47). They are completely separated from each other by the membranous partition just described, the mediastinum. Between the two folds of the mediastinum, namely, in the middle of the chest, but inclining somewhat to the left side, is placed the heart, enveloped in another serous membrane, the pericardium (Fig. 47).

The lungs are moulded to the cavities they fill; whence their figure is conical, the base of the cone being downwards, resting on the diaphragm; and the apex upwards, towards the neck.

That surface of each lung which corresponds to the walls of the chest is convex in its whole extent; on the contrary, that surface which corresponds to the mediastinum is flattened (Fig. 48). The basis of the lung is concave, adapted to the convexity of the diaphragm on which it rests.

The air-vessel of the lungs, termed the bronchus, and the blood-vessels and nerves, enter the organ at its flattened side, not exactly in the middle, but rather towards the upper and back part (Fig. 48). This portion is termed the root of the lung.

Fig. 47.

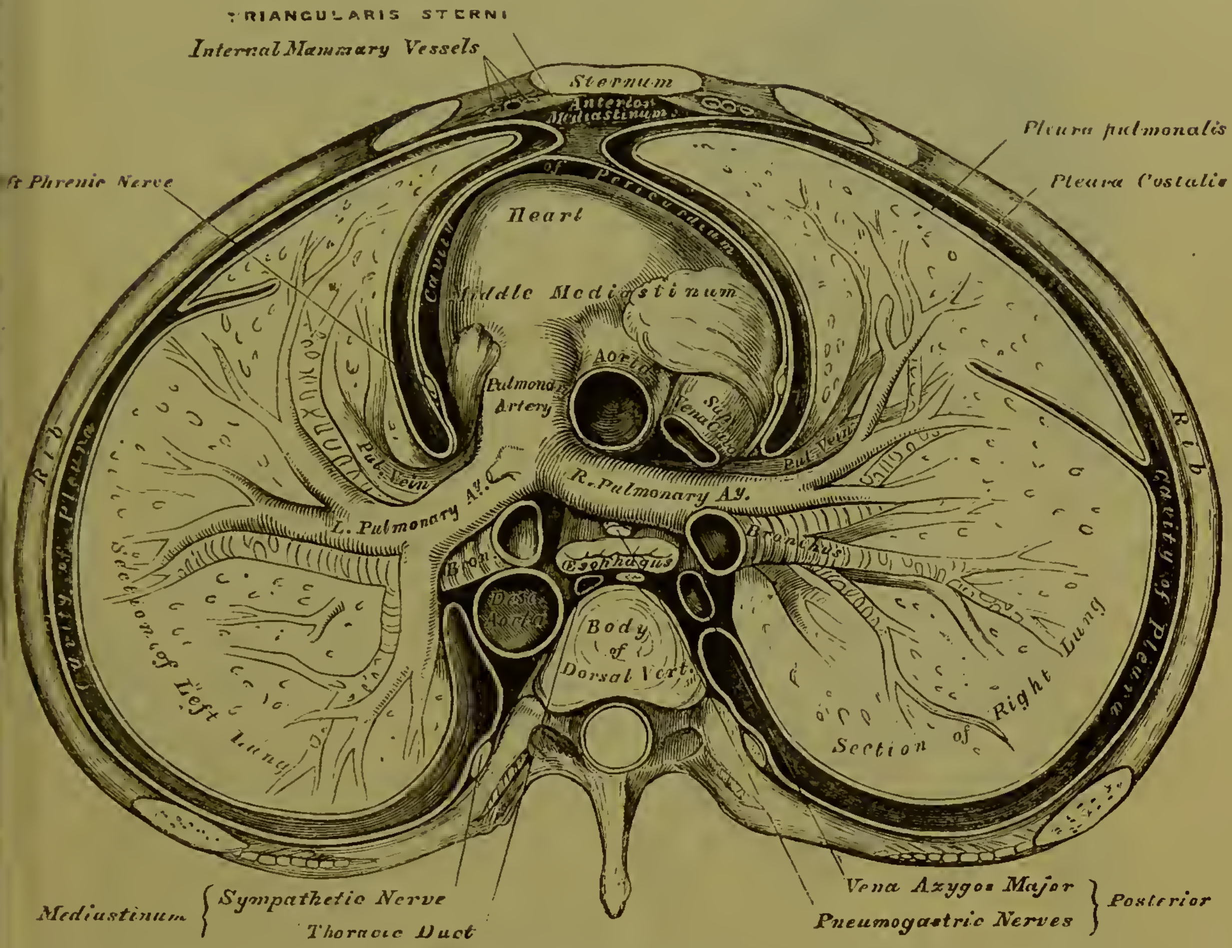


Front view of the heart and lungs.

The lungs are attached to the neck by the trachea (Fig. 47), the continuation of which forms the bronchus; to the spinal column by the pleura, and to the heart by the pulmonary vessels (Fig. 47): their remaining portion is free and unattached.

In the living body, the lungs on each side completely fill the cavity of the chest, following passively the movements of its walls, and accurately adapting themselves to its size, whether its capacity enlarge in inspiration, or diminish in expiration, so that the external surface of the lung (the pulmonary pleura) is always in immediate contact with the lining membrane of the walls of the cavity (the costal pleura); consequently, during life there is no cavity, the chest being always completely full.

Fig. 48.

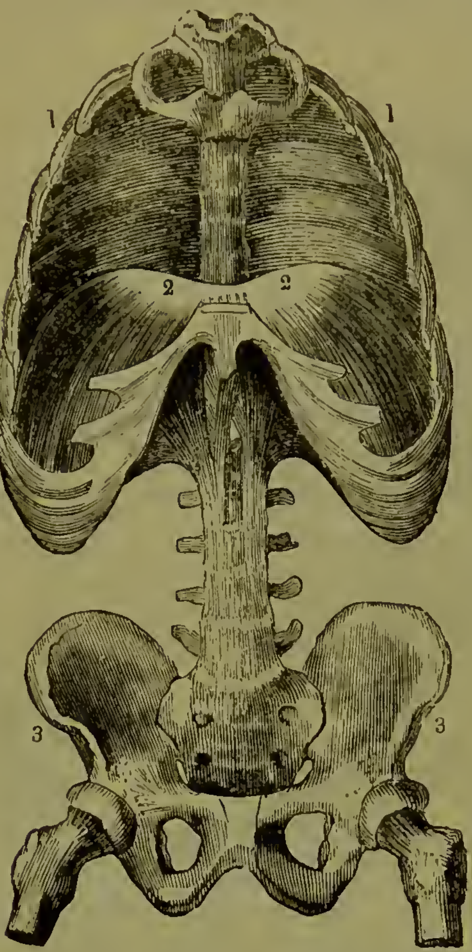


A transverse section of the thorax, showing the relative position of the viscera, and the reflections of the pleuræ.

The anterior surface of the pericardium, the bag which envelopes the heart, lies immediately behind the sternum, and the cartilages of the second, third, fourth, and fifth ribs, covered at its sides by the pleura, and firmly attached below to the diaphragm (Fig. 47).

Surrounded by its pericardium, within the mediastinum, the heart is placed nearly in the centre of the chest; but its direction is somewhat oblique, its apex being directly opposite to the interval between the fifth and sixth ribs on the left side; while its basis is directed upwards, backwards, and towards the right. That portion of its surface which is presented to view on opening the pericardium is convex; but its opposite surface, namely, that which rests upon the part of the pericardium which is attached to the diaphragm, is flattened. It is fixed in its situation partly by the pericardium and partly by the great vessels that go to and from it. But under the different states of expiration and inspiration, it accompanies, in some degree, the movements of the diaphragm; and in the varied postures of the body the heart deviates to a certain extent from the exact position here described.

Fig. 49.



View of the diaphragm. 1, cavity of the thorax; 2, diaphragm separating the cavity of the thorax from that of the abdomen; 3, cavity of the pelvis.

The second division of the trunk, the *abdomen*, is bounded above by the diaphragm (Fig. 49, 2), below by the pelvis (Fig. 49, 3), behind and at the sides by the vertebræ and muscles of the loins, and before by the abdominal muscles.

The organ which forms the superior boundary of the abdomen, the diaphragm (midriff), is a circular muscle, placed transversely across the trunk, nearly at its centre (Fig. 49, 2). It forms a vaulted partition between the thorax and the abdomen. All around its border it is fleshy; towards its centre it is tendinous; the surface towards the abdomen is concave; that towards the thorax convex; while its middle tendinous portion ascends into the thorax as high as the fourth rib.

The diaphragm is perforated by several apertures, for the transmission of tubes and vessels, which pass reciprocally between the thorax and abdomen.

1. A separate aperture is formed to afford an exit from the thorax of the aorta, the common source of the arteries, and an entrance into the thorax of the thoracic duct, the tube that bears the digested aliment to the heart. 2. A little to the left of the former there is another aperture, through which passes the œsophagus or gullet, the tube that conveys the food from the mouth to the stomach. 3. On the right side, in the tendinous portion of the diaphragm, very carefully constructed, is a third aperture for the passage of the vena cava, the great vessel that returns the blood to the heart from the lower parts of the body.

The partition formed by the diaphragm between the thorax and abdomen, though complete, is moveable; for, as the diaphragm descends in inspiration and ascends in expiration, it proportionally enlarges or diminishes the cavities between which it is placed; consequently, the actual magnitude of these cavities varies every moment, and the size of the one is always in the inverse ratio of that of the other.

Between the abdomen and the pelvis there is no separation; one cavity is directly continuous with the other (Fig. 50); but along the inner surface of the expanded bones, which form a part of the lateral boundary of the abdomen, there is a prominent line, termed the brim of the pelvis, marking the point at which the abdomen is supposed to terminate and the pelvis to commence.

Behind and at the sides the walls of the abdomen are completed, partly by the lumbar portion of the spinal column, and partly by the lumbar muscles, and before by the abdominal muscles.

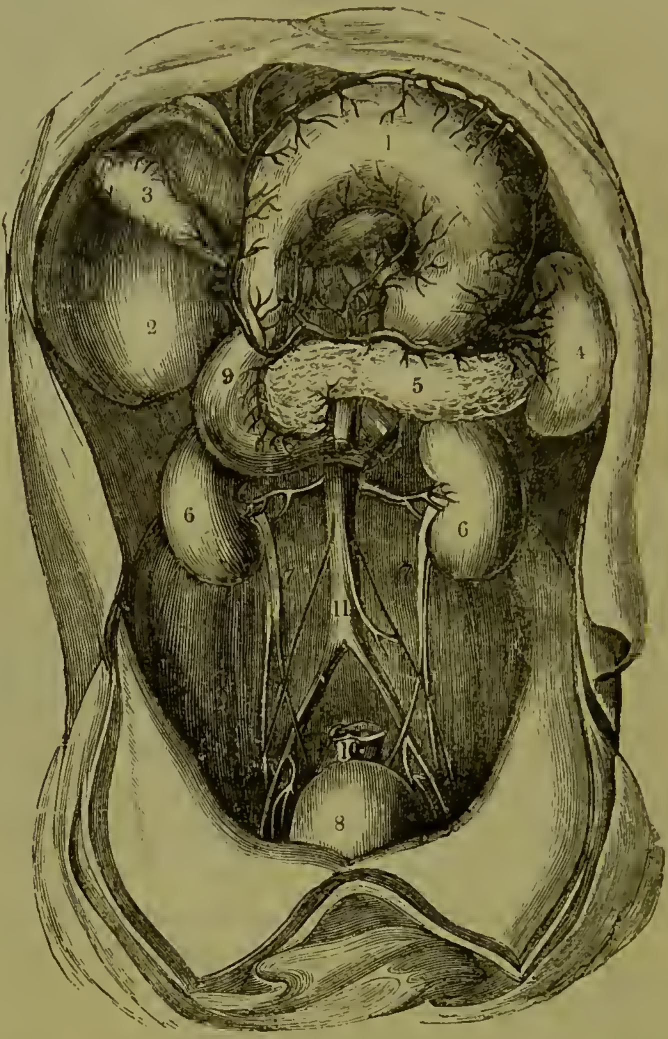
The inner surface of the walls of the abdomen is lined throughout by a serous membrane, termed the peritoneum. From the walls of the abdomen, the peritoneum is reflected upon the organs contained in the cavity, and is continued over them so as to form their external coat. The peritoneum also descends between the several organs, connecting them together, and holding them in their situation; and it likewise forms numerous folds, in which are embedded the vessels and nerves that supply the organs. It secretes a serous fluid, by which its own surface and that of the organs it covers is rendered moist, polished, and glistening, and by means of which the organs glide smoothly over it, and over one another in the various movements of the body, and are in constant contact without growing together. In structure, distribution, and function, the peritoneum is thus perfectly analogous to the pleura.

Like the thorax, the abdomen is always completely full. When the diaphragm is in action, it contracts. When the diaphragm is in the state of contraction, the abdominal and lumbar muscles are in the state of relaxation. By the contraction of the diaphragm, the organs contained in the abdomen are pushed downwards, and the anterior and lateral walls of the cavity being at this moment in a state of relaxation, they readily yield, and, consequently, the viscera are protruded forwards and at the sides. But the abdominal and lumbar muscles, in their turn, contract, the diaphragm relaxing; and, consequently, the viscera, forced from the front and sides of the abdomen, are pushed upwards, together with the diaphragm, into the thorax. A firm and uniform pressure is thus, at all times, maintained upon the whole contents of the abdomen: there is an exact adaptation of the containing to the contained parts, and of one organ to another. No space intervenes either between the walls of the abdomen and the organs they enclose, or between one organ and another; so that the term cavity does not denote a void or empty space, but merely the extent of the boundary within which the viscera are contained.

The contents of the abdomen consist of the organs which belong to the apparatus of digestion, and of those which belong to the apparatus of excretion.

The organs which belong to the apparatus of digestion are—1. The stomach (Figs. 50, 1, and 51). 2. The duodenum (Figs. 50, 9, and 51).

Fig. 50.



General view of the viscera of the abdomen. 1, stomach raised; 2, under surface of liver; 3, gall bladder; 4, spleen; 5, pancreas; 6, kidneys; 7, ureters; 8, urinary bladder; 9, portion of the intestine called duodenum; 10, portion of the intestine called rectum; 11, the aorta.

3. The jejunum (Fig 51). 4. The ilium (Fig. 51). The three last organs are called the small intestines, and their office is partly to carry on the digestion of the aliment commenced in the stomach, and partly to afford an extended surface for the absorption of the nutriment as it is prepared from the aliment. 5. The pancreas (Fig. 50, 5). 6. The liver (Fig. 50, 2). 7. The spleen (Fig. 50, 4). The three last organs truly belong to the apparatus of digestion, and their office is to co-operate with the stomach and the small intestines in the conversion of the aliment into nutriment.

The organs which belong to the apparatus of excretion are—1. The

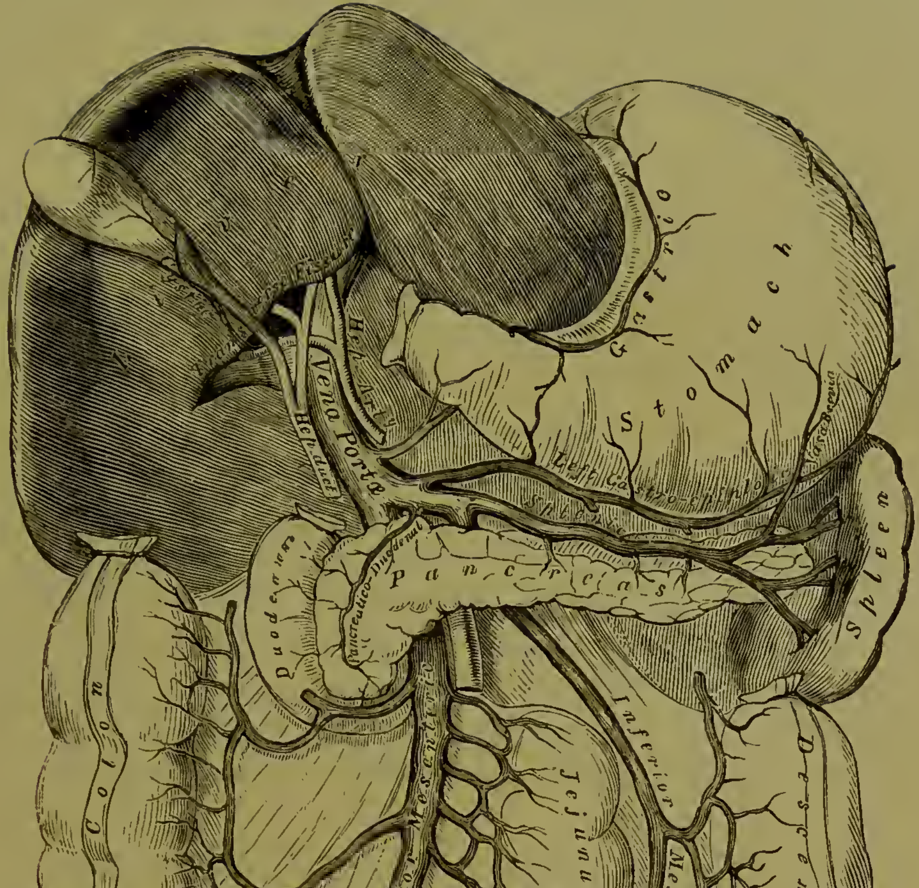


Fig. 51.—Portal vein and its branches.

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large intestines consisting of the cæcum. 2. The colon (Fig. 51). 3. The rectum (Fig. 51). It is the office of these organs, which are called the large intestines, to carry out of the system that portion of the alimentary mass which is not converted into nourishment. 4. The kidneys (Fig. 50, 6), the organs which separate in the form of the urine an excrementitious matter from the blood, in order that it may be conveyed out of the system.

The last division of the trunk, called the pelvis (Fig. 49, 3), consists of a circle of large and firm bones, interposed between the lower portion of the trunk and the inferior extremities. The bones that compose the circle are firmly united in the adult into a single piece; they are always described as separate bones. They are the sacrum, the coccyx, the ilium, the ischium, and the pubis.

The sacrum, placed like a wedge between the moveable portion of the spinal column and the lower extremities, forms the posterior boundary of the pelvis. The figure of this bone is triangular; its anterior surface is concave and smooth, for enlarging the cavity of the pelvis, and sustaining the organs contained in it; its posterior surface is convex, irregular, and rough (Fig. 42), giving origin to the great muscles that form the contour of the hip, and to the strong muscles of the back and loins that raise the spine and maintain the trunk of the body erect.

The base or upper part of the sacrum receives the last vertebra of the loins on a large and broad surface, forming a moveable joint; and the degree of motion at this point is greater than it is at the higher points of the spinal column. Firmly united at its sides with the haunch bones, it admits there of no degree of motion.

The coccyx, so named from its resemblance to the beak of the cuckoo, when elongated by a succession of additional bones, forms the tail in quadrupeds; but in man it is turned forwards to support the parts contained in the pelvis, and to contract the lower opening of the cavity. By means of a layer of cartilage, the medium by which this bone is connected with the sacrum, it forms a moveable articulation, continuing moveable in men until the age of twenty-five, and in women until the age of forty-five; continuing moveable in women thus long, in order that by yielding to the force which tends to push it backwards during the period of labour, it may enlarge the lower aperture of the pelvis, and so facilitate the process of parturition and diminish its suffering.

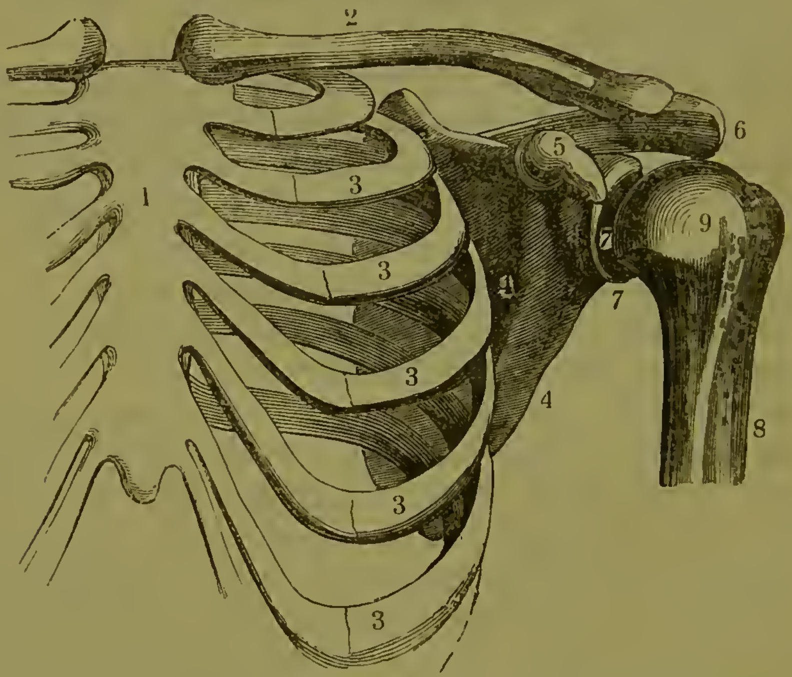
The lateral boundaries of the pelvis are formed by the ilium (Fig. 31), and by the ischium (Fig. 31). The ilium forms the lower part of the abdomen and the upper part of the pelvis; its broad expanded wing supports the contents of the abdomen, and gives attachment to the muscles that form the anterior portions of its walls; its external convex surface sustains the powerful muscles that extend the thigh; and along its internal surface is the prominent line which marks the brim of the pelvis, and which divides this cavity from that of the abdomen.

The ischium is the lower part of the pelvis (Fig. 31); at its undermost portion is a rounded prominence called the tuberosity, in its natural condition covered with cartilage, upon which is superimposed a cushion of fat. It is the part on which the body is supported in a sitting posture.

The pubis or share bone forms the upper and fore part of the pelvis (Fig. 31), and together with the two former bones, completes the large and deep socket, termed the acetabulum (Fig. 31), into which is received the head of the thigh bone. The margin of the acetabulum and the greater part of its internal surface is lined with cartilage, so that in its natural condition it is much deeper than it appears to be when the bones alone remain.

The lower aperture of the pelvis, which appears large when all the soft parts are removed, is not really large, for in its natural state it is filled up partly by muscles and partly by ligaments, which sustain and protect the pelvic organs, leaving only just space enough for the passage to and from those which have their opening on the external surface.

Fig. 52.



1, Sternum; 2, clavicle; 3, ribs; 4, anterior surface of scapula; 5, coracoid process of scapula; 6, acromion process of scapula; 7, margin of glenoid cavity of scapula; 8, body of the humerus or bone of the arm; 9, head of the humerus.

The cavity of the pelvis, together with all the organs contained in it, are lined by a continuation of the membrane that invests the abdomen and its contents.

The organs contained in the pelvis are the rectum (Fig. 51), which is merely the termination of the large intestines, the urinary bladder (Fig. 50, 8), and the internal part of the apparatus of reproduction.

The large and strong bones of the pelvis not only afford lodgment and protection to the tender organs contained in its cavity, but sustain the entire weight of the body, the trunk resting on the sacrum as on a solid basis, and the lower extremities being supported in the sockets in which the heads of the thigh bones play, in the varied movements of locomotion.

The last division of the body comprehends the superior and the inferior extremities.

The superior extremities consist of the shoulder, arm, fore-arm, and hand.

The soft parts of the SHOULDER are composed chiefly of muscles; its bones are two—the scapula or the *blade bone,* and the clavicle or the *collar bone* (Fig. 52, 2, 4).

The SCAPULA is placed upon the upper and back part of the thorax, and occupies the space from the second to the seventh ribs (Fig. 52, 4). Unlike that of any other bone of the body, it is embedded in muscles, without being attached to any bone of the trunk, excepting at a single point. From the bones of the thorax it is separated by a double layer of muscles, on which it is placed as upon a cushion, and over the smooth surface of which it glides. Originally, like the bones of the skull, it consisted of two tables of compact bones, with an intermediate layer of spongy bony substance (diploë); but, by the pressure of the muscles that act upon it, it gradually grows thinner, until, as age advances, it becomes in some parts quite transparent, and as thin as a sheet of paper.

The figure of the scapula is that of an irregular triangle (Fig. 52). Its anterior surface is concave, corresponding to the convexity of the ribs; its posterior surface is very irregular, being in some parts concave, and in others convex, giving origin especially to two large processes; one of which is termed the *acromion* (Fig. 52, 6), and the other the *caracoid* process of the scapula (Fig. 52, 5). The margins of the bone, whatever the thinness of some portions of it, are always comparatively thick and strong, affording points of origin or of insertion to powerful muscles. At what is called the anterior angle of the bone there is a shallow oval depression, covered with cartilage and deepened by a cartilaginous margin, called the *glenoid* cavity of the scapula (Fig. 52, 7), which receives the head of the humerus or bone of the arm (Fig. 52, 9).

The clavicle, the second bone of the shoulder, is a long and slender bone, of the form of an italic ⁓, projecting a little forwards towards its middle, so as to give a slight convexity of outline to the top of the chest and the bottom of the neck (Fig. 52, 2). It is attached by one extremity to the sternum and by the other to the scapula, by moveable joints. In the connexion of the bones of the trunk, while the main object is to secure firmness of attachment, some degree of motion is at the same time obtained: but the mode in which the several bones of the extremities are connected with each other and with the trunk, admits of so great a degree of motion, that these articulations are pre-eminently entitled to the name of moveable joints. The component parts of all moveable joints are bone, cartilage, synovial membrane, and ligament. The great character of a moveable joint is the approximation of two or more bones; yet these bony surfaces are never in actual contact, but are invariably separated from each other by cartilage. The cartilage either covers the entire extent of the articulating surface of the bones, as in the shoulder-joint, where both the head of the humerus and the cavity of the scapula that receives it are enveloped in this substance, or a portion of it is placed between the articulating surfaces of the bones, as in the joint between the clavicle and sternum, which, when so placed, is termed an inter-articular cartilage. By its smooth surface cartilage lessens friction; while, by its elasticity, it facilitates motion and prevents concussion. Slightly organised cartilage is provided with comparatively few blood-vessels and nerves. Had it been vascular and sensible, like the skin and the muscles, the force applied in the movements of the joint would have stimulated the blood-vessels to inordinate action, and the sensibility of the nerves would have been the source of constant pain: every motion of every joint would have been productive of suffering, and have laid the foundation of disease. The facility and ease of motion obtained by the smoothness, elasticity, and comparative insensibility of cartilage are still further promoted by the fluid which lubricates it, termed synovia, secreted by a membrane called synovial, which lines the internal surface of the joint, and which bears a close resemblance to the serous. Synovia is a viscid fluid of the consistence of albumen. It is to the joint what oil is to the wheel, preventing abrasion and facilitating motion; but it is formed by the joint itself, at the moment when needed, and in the quantity required. The motion of the joints stimulates the synovial membrane to secretion, and hence the greater the degree of motion, the larger the quantity of lubricating fluid that is supplied. The several parts of the apparatus of moveable joints are retained in their proper position by ligamentous substance, which, as has been shown, is oftentimes so strong that it is easier to fracture the bone than to tear the ligament, and in every case the kind and extent of motion possessed by the joint are dependent mainly on the form of the articulatory surfaces of the bones and on the disposition of the ligaments.

In the joint formed by the clavicle and the sternum, an inter-articular cartilage is placed between the two bones which are united, first by a strong fibrous ligament, which envelops them as in a capsule; by a second ligament which extends from the cartilage of the first rib to the clavicle, by which the attachment of the clavicle to the sternum is materially strengthened; and by a third ligament which passes transversely from the head of one clavicle to that of the other. The joint thus formed, though so strong and firm that the dislocation of it is exceedingly rare, yet admits of some degree of motion in every direction, upwards, downwards, forwards, and backwards; and this articulation is the sole point by which the scapula is connected with the trunk, and, consequently, by which the upper extremity can act, or be acted upon, by the rest of the body.

The scapular extremity of the clavicle is attached to the processes of the scapula by several ligaments of great strength. First, by very strong fasciculi which pass from the upper surface of the clavicle to the acromion of the scapula; and, secondly, by two ligaments which unite the clavicle with the coracoid process of the scapula. These ligaments are so powerful that they resist a force capable of fracturing the clavicle; and they need to be thus strong, for the clavicle is a shaft which sustains the scapula, and through the scapula the whole of the upper extremity; and the main object of the joint by which these bones are united, is to afford a firm attachment of the scapula to its point of support.

The clavicle serves the following uses: it sustains the upper extremity; it connects the upper extremity with the thorax; it prevents the upper extremity from falling forwards upon the thorax; and it affords a fixed point for steadying the extremity in the performance of its various actions.

The glenoid cavity of the scapula (Fig. 52, 7), receives the head of the humerus, the bone of the arm (Fig 52, 9), and the two bones, being united by ligament, form the shoulder-joint. This joint is what is termed a ball and socket joint, the peculiarities of which are two: first, beyond all others, this mode of articulation admits of free and extensive motion; in the present case, there is the utmost freedom of motion in every direction, upwards, downwards, backwards, and forwards. In the second place, this mode of articulation admits of the motion of the limb without that of the body, or of the motion of the body without that of the limb. When at rest, the arm may be moved in almost any direction without disturbing the position of any other part of the frame; the manifold advantages of which are obvious. On the other hand, by careful management, very considerable variations in the posture of the body may be effected without the communication of any degree of motion to the limb; an unspeakable advantage when the limb has sustained injury, or is suffering from disease.

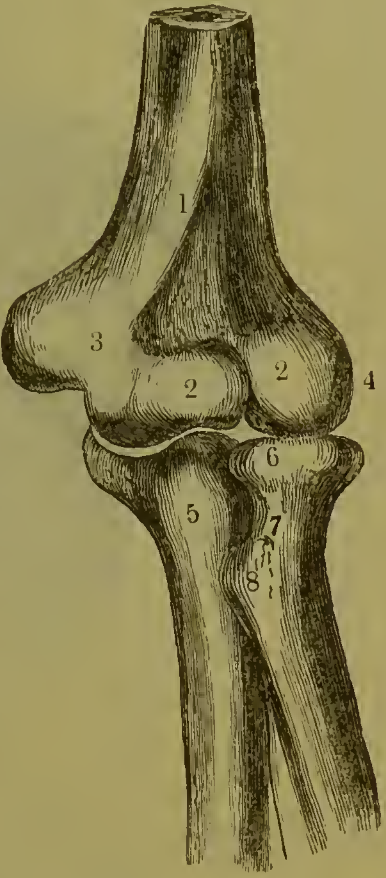
It does not seem possible to construct a joint of great strength, capable, at the same time, of the degree of motion possessed by the joint of the shoulder. So shallow is the socket of the scapula, and so large the head of the humerus, that it seems as if the slightest movement must dislodge it from its cavity. For sustaining heavy weights or resisting a great amount of pressure, applied to it suddenly and in various directions, the arm is obviously unfitted. But this is not its office. The superior extremities are the organs of apprehension—the instruments by which the mind executes the commands of the will. They do not need the strength required by the organs that sustain the weight of the body and that perform the function of locomotion; but they do need freedom and extent of motion: to this strength may be sacrificed, and so it is; yet what can be done to combine strength with mobility is effected. Large and strong processes of bone, proceeding, as has been shown, from the convex surface of the scapula (Fig. 52) overhang, and to a considerable extent surround, the head of the arm-bone, especially resisting the force that would dislodge it from its socket, and drive it upwards, inwards, and backwards (Fig. 52), the directions in which force is most commonly applied to it. By these processes of bone the joint is greatly protected, especially in those directions. Moreover, a strong ligament, termed the fibrous capsule, envelops the joint. This ligament, arising from the neck of the scapula (Fig. 59), expands itself in such a manner as completely to surround the head of the humerus (Fig. 59); and then again contracts in order to be inserted into the neck of the bone. This ligament is strengthened by the tendons of no less than four muscles which are expanded over it. In addition to all these expedients for fortifying the joint, it receives a further security from the mobility of the scapula, which slides easily over the ribs upon its cushion of flesh; and thus obtains, by facility of yielding, some compensation for its want of strength, giving way before the force which it cannot resist.

The arm consists of numerous and powerful muscles, and of a single bone, the humerus, which belongs to the class of bones termed cylindrical.

The upper end of the humerus terminates in a hemispherical head (Fig. 52, 9), which is received into the socket of the scapula (Fig. 52, 9, 7) termed, as has been stated, its glenoid cavity. The middle portion of the bone, or what is termed its shaft (Fig. 52, 8), diminishes considerably in magnitude, and becomes somewhat rounded, while its lower end is flattened before and behind, and ends below in a smooth grooved surface resembling one moiety of an ordinary hinge.

The grooves are fitted to corresponding elevations on the upper end of the bones of the fore-arm, and form the elbow-joint: just above the articular end there is on each side of the bone a projection called condyle (Fig. 53, 3, 4), the inner (Fig. 53, 3) being much larger than the outer (Fig. 53, 4). The inner condyle gives origin to the muscles that bend, the outer to those that extend the fore-arm and the fingers.

Fig. 53.



1, Lower extremity of the humerus; 2, grooved surface; 3, internal condyle; 4, external condyle; 5, the upper part of the ulna; 6, the head; 7, the neck; 8, the tubercle of the radius.

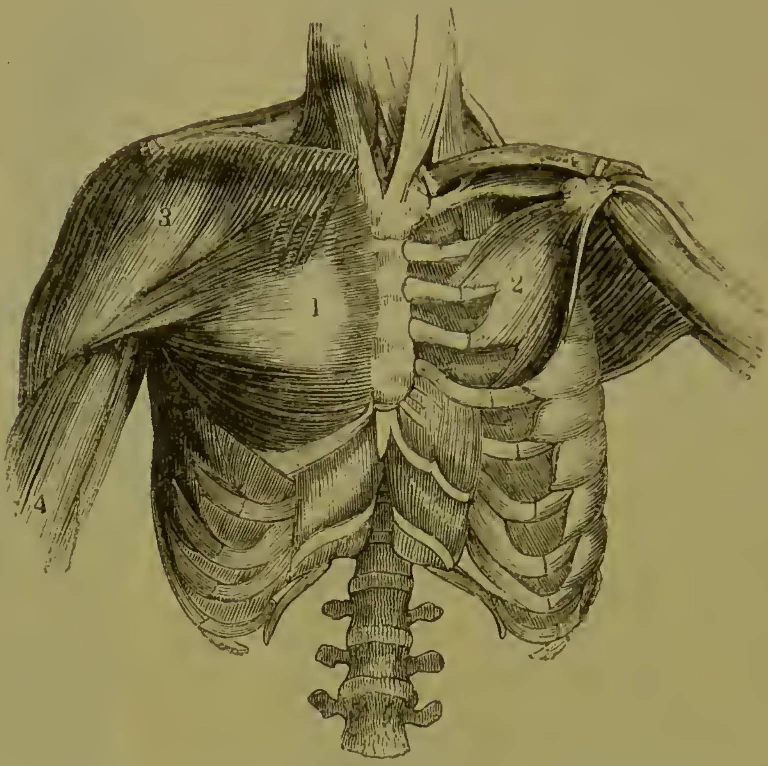
The muscles that act upon the arm arise from the back, the chest, the clavicle, and the scapula; and they move the arm with freedom and power upwards, downwards, forwards, backwards, inwards, and outwards. The chief muscle that raises the arm is the deltoid (Figs. 54 and 55, 3), which arises partly from the clavicle, and partly from the scapula (Fig. 54). It has the appearance of three muscles proceeding in different directions, the different portions being separated by slight fissures. The fibres converging unite and form a powerful muscle, which covers the shoulder-joint (Fig. 54). It is implanted by a short and strong tendon into the middle of the humerus. Its manifest action is to raise the arm. Its action is assisted by the muscles that cover the back of the scapula, which are inserted about the neck of the humerus, and which, at the same time that they elevate the arm, support it when raised.

When the arm is raised by the deltoid and its assistant muscles, the latissimus dorsi (Fig. 55, 2) carries it downwards and towards the back, whilst the greater pectoral (Fig. 54), carries it downwards and towards the chest.

The latissimus dorsi is the broadest muscle of the body, and after having covered all the lower part of the back and loins, terminates in a thin but strong tendon, which stretches to the arm. The fibres of the pectoralis, arising partly from the sternum and cartilage of the ribs near that bone, and partly from the clavicle, are gathered upon a strong tendon. These two great muscles, stretching from the body to the arm, form the boundaries of the armpit before and behind, and are attached near each other to the humerus, about four inches below its head.

These actions are aided and modified by smaller muscles, that stretch from the scapula to the upper end of the humerus; and by the combination of all these, the arm can be moved and turned in any direction.

Fig. 54.



View of the muscles on the fore part of the chest that act upon the arm. 1, the muscle called the great pectoral; 2, the small pectoral; 3, the deltoid; 4, the humerus.

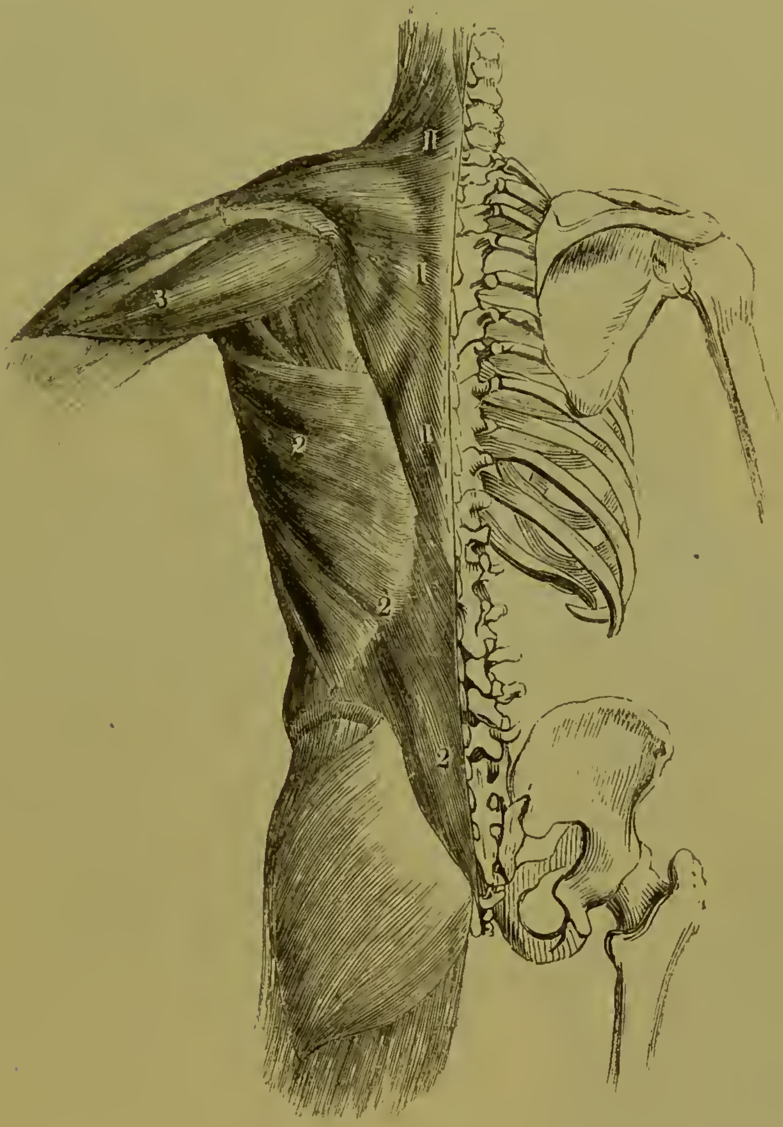
It has been already stated that the shoulder-joint is completely surrounded by the muscular fibres or the tendinous expansions of several of these powerful muscles, which have a far greater effect in maintaining the head of the humerus in its socket than the fibrous capsule of the joint; the latter being necessarily loose, in order to allow of the extended and varied motions of the arm, whereas the muscles that encompass the joint adhere closely and firmly to it. Moreover, by virtue of their vital power, these muscles act with an efficiency which a mere ligamentous band is incapable of exerting; for they apportion the strength of resistance to the separating force, and react with an energy proportioned to the violence applied.

The bones of the fore-arm are two, the ulna and the radius (Figs. 31, and 53, 5 and 7).

When one looks at the palm of his own hand, the radius is on the outer, and the ulna on the inner side of the fore-arm. The larger end of the ulna is at the elbow, whilst the larger end of the radius is at the wrist.

The upper ends of these bones are, for the most part, on the same level, but the top of the ulna grows up behind into a stout projection, which is called the elbow or olecranon (Fig. 56); the hinder surface of this is covered with coarse skin, as if nature intended it for a part on which we may occasionally lean and rest, whilst its fore surface is adapted to the humerus, and helps to strengthen the elbow-joint. The top of the radius, which is cup-like and hollow, placed beside the top of the ulna and its great projection, which are marked with a longitudinal ridge separating two furrows, together form a many-grooved surface (Fig. 56), and this fits closely the lower end of the humerus before described, in such a way, that whilst movement forward and backward is very free, there is no lateral motion whatever allowed; the joint is, therefore, a hinge joint, of which the two motions of flexion and extension are the proper motions. The bones at this joint are held together by a strong ligament on each side, the inner (Fig. 55) connecting the humerus

Fig. 55.



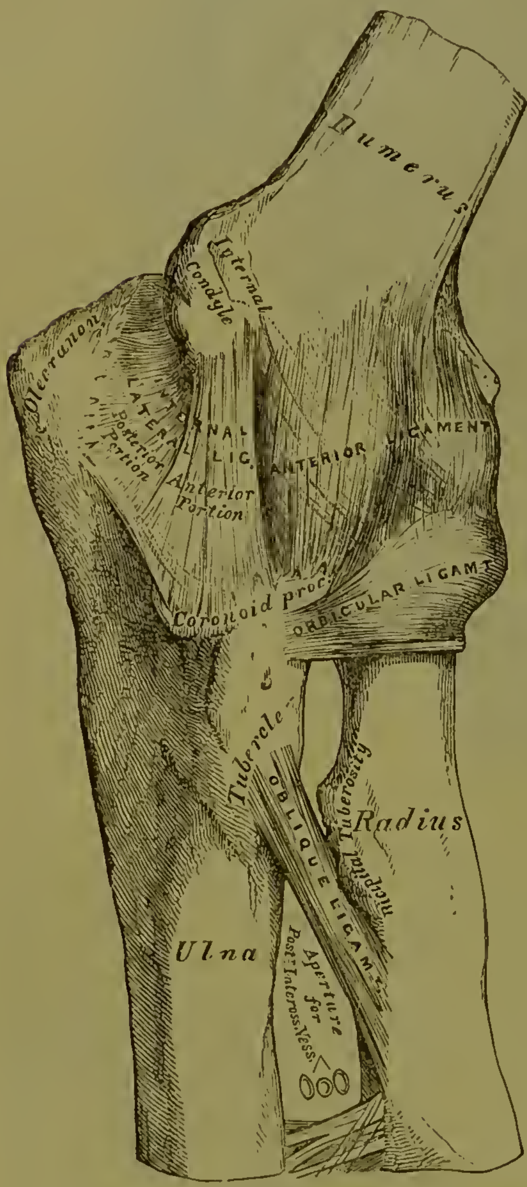
View of the muscles seated on the back part of the trunk that act upon the shoulder and arm. 1, the muscle called the trapezius; 2, the latissimus dorsi; 3, the deltoid.

to the ulna, the outer connecting the humerus not to the radius,—for that would prevent the rotary movement of that bone on the ulna in pronation of the hand, but to the ligamentous collar (Fig. 56) in which the head of the radius works. In front and at the back of the joint are very thin ligaments, which are connected with the muscles that pass over them, so as to be held off the ends of the bones in their movements, and kept by this beautiful provision from being pinched between them. The upper and lower ends of the bone of the fore-arm are in contact, but their shafts part away from each other, and are connected by a band of strongly woven membrane (Fig. 56); the rounded upper end of the radius fits in a concavity on the side of the ulna above, whilst conversely, the rounded lower end of the ulna fits to a concavity on the side of the radius below, and at the places of contact the ends are covered with cartilage, and connected by ligaments to form joints. Whilst the upper end of the radius turns on its own axis in a ring (Fig. 56), formed partly by the ulna and partly by a ligamentous collar, the lower turns on the rounded end of the ulna. It is in this way that the radius, by its lower end, which carries the wrist and hand, moves round the lower end of the ulna, describing a semicircle, whilst the back or palm of the hand is turned forward at will, the upper end in the elbow-joint being all the while stationary, and only rotating on its axis.

The hinge-like joint of the elbow admits of two movements only—flexion and extension.

The muscles which execute these movements constitute the chief bulk of the upper arm—the two flexors placed on the front of the bone and the extensors on the back.

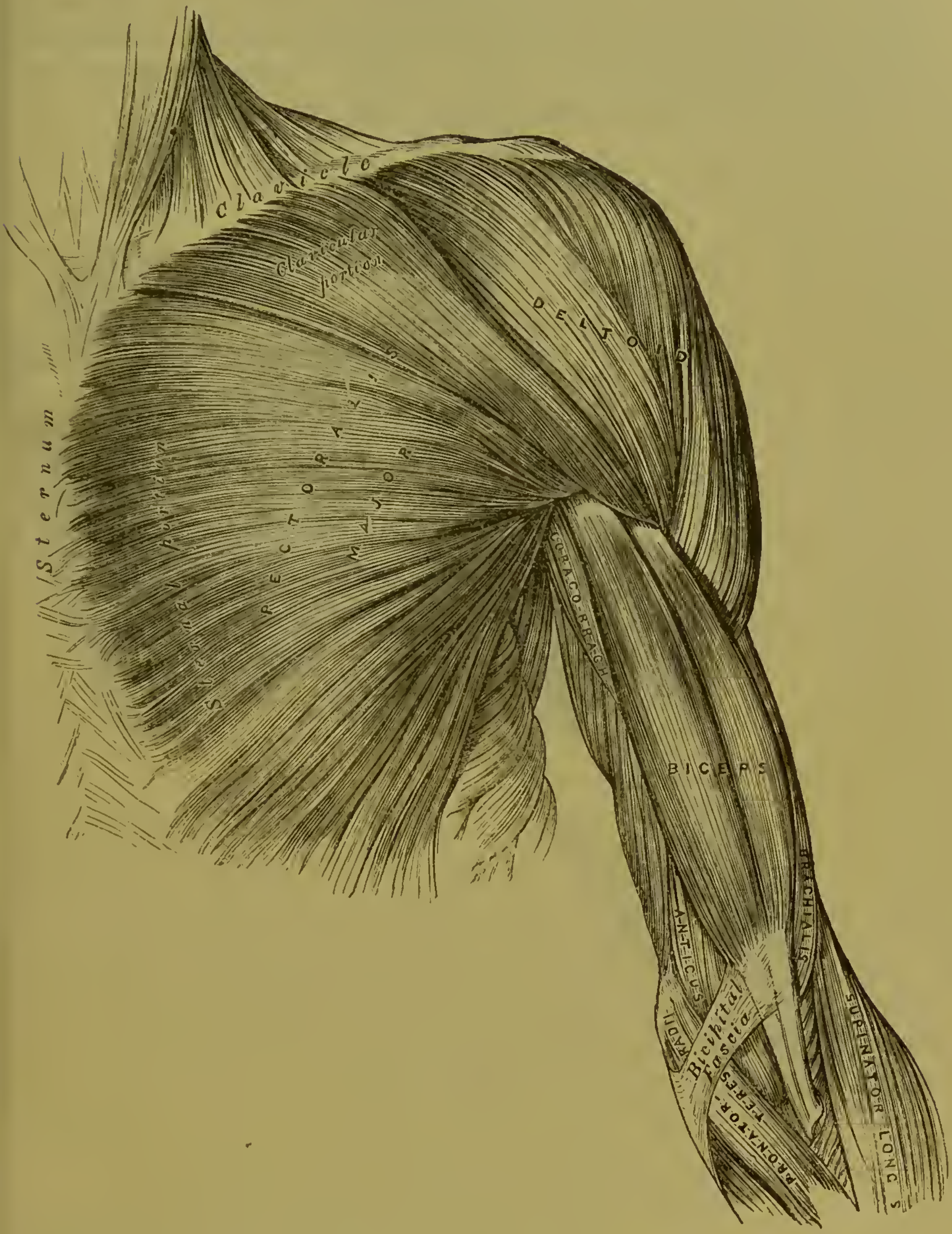
Fig. 56.



Left elbow-joint, showing anterior and internal ligaments.

Of the flexors, one is attached to each bone of the fore-arm, and in the arm one overlies the other; the more superficial is called biceps

Fig. 57.

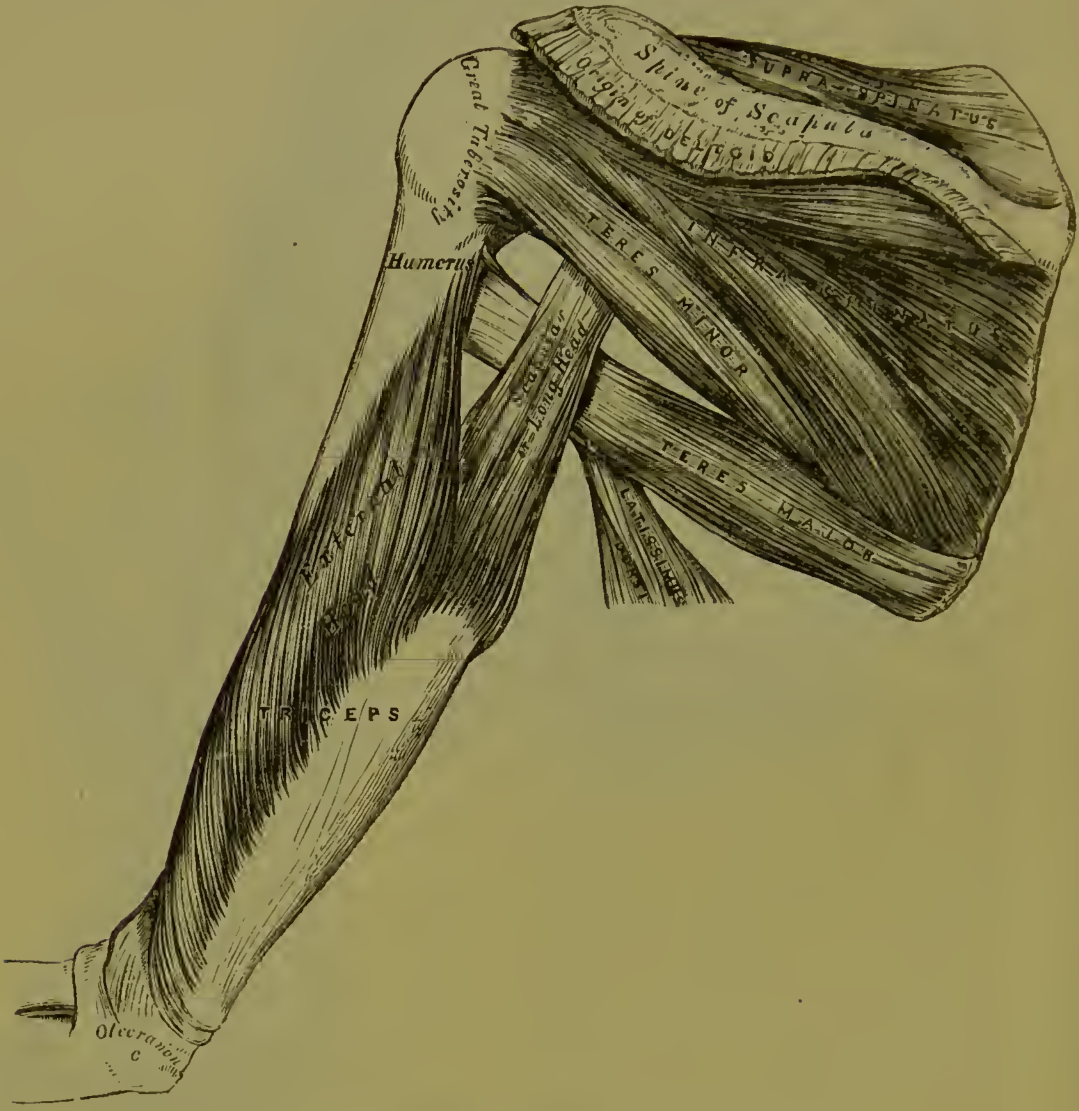


Muscles of the chest and front of the arm. Superficial view.

(Fig. 57). Coming by two heads from the scapula, it is attached to the side of the neck of the radius towards the back of the bone, and behind a prominence, which adds considerably to the leverage in one of its actions, viz., the rolling of the radius on its axis in supination; for the muscle, besides bending the arm, is one of the most efficient agents in turning the wrist, as in the movement of driving a screw, its contracted mass forms the ball-like prominence which arises in the arm when the forearm is forcibly flexed.

The second flexor is termed Brachialis-anticus (Fig. 57); it comes from the fore surface of the lower half of the humerus, and is attached by a strong tendon to the ulna. This muscle is almost concealed by the biceps, and both muscles are thick, fleshy, and powerful.

Fig. 58.



Muscles on the dorsum of the scapula and the triceps.

The great extensor is placed (Fig. 58) behind the arm-bone, and is called triceps, from its arising in three parts: one from the scapula, the other two less separate from the humerus; they are gathered upon a strong tendon, which is implanted upon the olecranon, or prominence of the elbow, the projection of which adds greatly to its effectiveness. Beside this great muscle, there is a small triangular slip, passing from the outer condyle of the humerus to the ulna, which aids in the

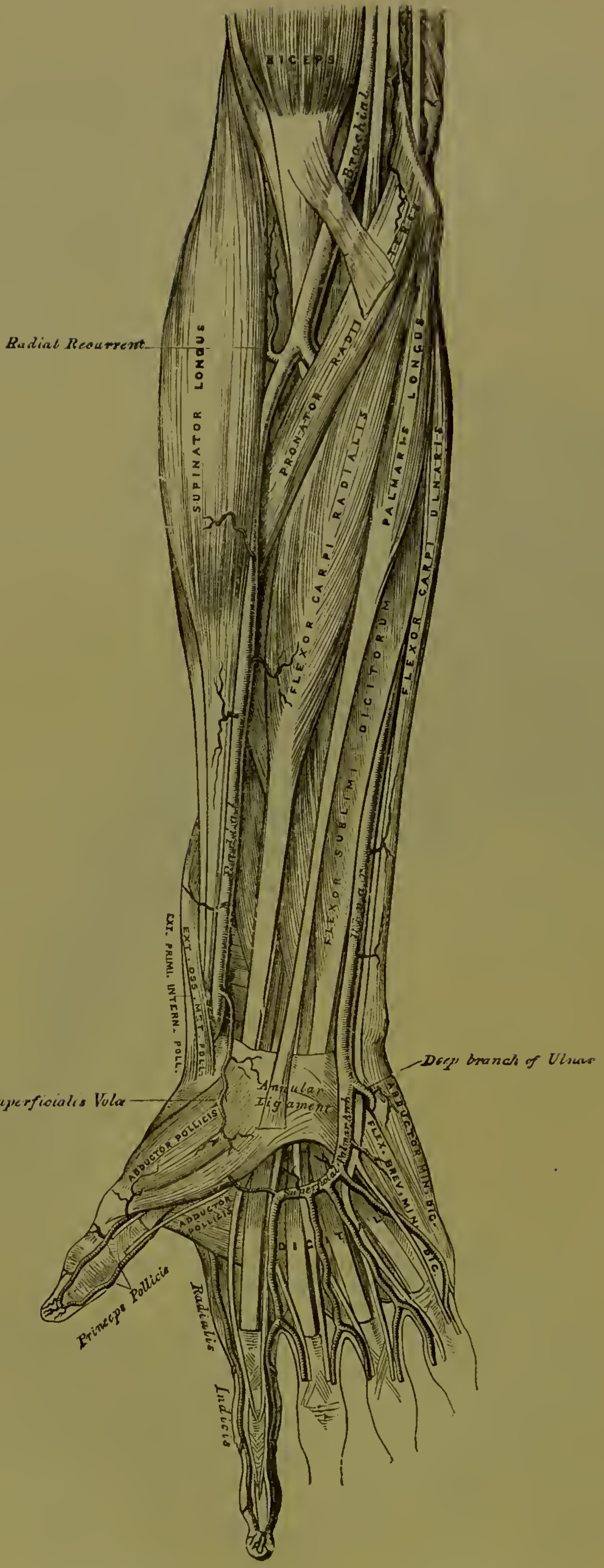


Fig. 59.—The surgical anatomy of the radial and ulnar arteries.

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extension of the fore-arm. Thus, the great extensors and flexors, grasping the same fixed points, draw upon the fore-arm, the former before the latter, behind the elbow-joint, each reversing the movement produced by the other.

We have before seen how the radius carrying the hand rolls upon the ulna, so as to turn up the palm. The movement of turning the palm up is called supination: when the palm is turned down the action is termed pronation.

The most powerful supinator is the biceps (Fig. 57), which rolls the radius before it raises it. There are two other supinators, both coming from the outer condyle of the humerus. The one, short and deeply-placed, encloses the upper third of the radius with its oblique fibres, which pass forward round the outside of the bone from behind, and above, so as in acting to roll it outwards. The long supinator (Figs. 57 and 58) is placed superficially, and comes from the outer side of the humerus to the lower end of the radius. It has scarce any action in supinating, but really flexes the fore-arm when the thumb is turned upwards and the biceps cannot act.

The round pronator (pronator teres, Fig. 59), from before and above, passes round the outside of the radius backwards.

Another small square muscle lies in front of the lower end of the bones, passing from the ulna to the radius.

The lower end of the bones of the fore-arm form the wrist-joint, with the bones of the carpus, to which the hand is attached (Fig. 31). There are eight little bones in the carpus, placed in two rows, with four to each row. Every bone fits by its sides to the bones next it in its own row: and the bones of the upper row are so placed as to compose together a convex surface, which plays freely on the lower end of the radius, whilst they show a concave socket, with a convexity on the outside of it towards the bones of the lower row. These have their shapes so disposed that they form a convex ball to fit the socket, and a concavity to fit the convexity on the outer side: whilst the two rows can move pretty freely, they are thus securely adapted by the interlocking of these eminences and pits.

The carpus is fitted to the metacarpus (Fig. 31), which forms the bony frame of the palm of the hand, and consists of five bones, four of which support the fingers, whilst the fifth supports the thumb, and is able to move freely in any direction. They are large at the ends where they are jointed to the carpus.

The upper ends are also adapted to each other by smooth flat surfaces, the lower are rounded to the cup-like ends of the phalanges. The shafts are narrowed to increase the spaces for muscles that move the fingers laterally. The adjacent edges and sides of the bones of the carpus and of the metacarpus are closely fastened by short ligaments

(Fig. 60), and the different rows are attached to each other, and the upper rows to the radius, by bands, which render the joint very strong. Though but little motion is allowed at each articulation, the sum of all the movements is considerable. The presence of so many little joints, allowing movement throughout the wrist, gives suppleness and pliability, with a capacity for yielding to shocks, whilst yet all its parts are strong and firmly united to resist displacement. Each finger is composed of three bones, called phalanges, the thumb has only two. The phalanges are smooth and rounded behind to increase strength, and are hollowed in front to fit the tendons that pass along them; they fit to each other, so that a double head on the nearer fits to a double cup on the farther little bone; the last bone is arrow-head shaped, expanding to support the nail and the sensitive tip of the finger. The phalanges are tied together by strong lateral ligaments, which only allow flexion and extension.

The movements of the wrist and hands are caused by muscles which occupy the fore-arm and palm of the hand. Those, with the supinators and extensors before mentioned, form its thickness over the surface of the bone. Some of the flexors are attached to the bones of the palm (flexor carpi radialis and f. c. ulnaris, Fig. 60), and serve to bend the wrist; others act on the fingers and thumb. These are very powerful muscles (f. sublimis digitorum, Fig. 60), and give two tendons to each finger, one to its last bone and one to the last but one. A beautiful piece of adaptation is seen here (Fig. 60). One of the flexor tendons overlies the other, and that which is superficial, when close to insertion, divides to let the deeper run through it beyond, to reach the last joint. The former thus serves to bind down the latter securely to its place.

From each of the deep flexor tendons in the palm a small worm-like muscle (lumbricalis, Fig. 60), rises, and runs to be inserted into the first phalanx.

The thumb and little finger have additional muscles (Fig. 60), which form the swelling on the inner and outer side of the palm of the hand: these muscles are flexors, and much increase the diversity of the movements and the grasping power of the thumb and little finger.

Long extensor muscles come down from the back of the fore-arm to the wrist and hand. Three of them (Fig. 61, ext. carp. rad. longior and brevior and e. c. ulnaris) end on the metacarpal bones, and act upon the wrist, whilst the remainder (ext. com. digitorum, Fig. 61) run into the finger, spreading over the back and attached to the bone. The index and little fingers have each an additional extensor, which confers more independence on their movements.

Small muscles (Fig. 60) placed between the metacarpal bones run

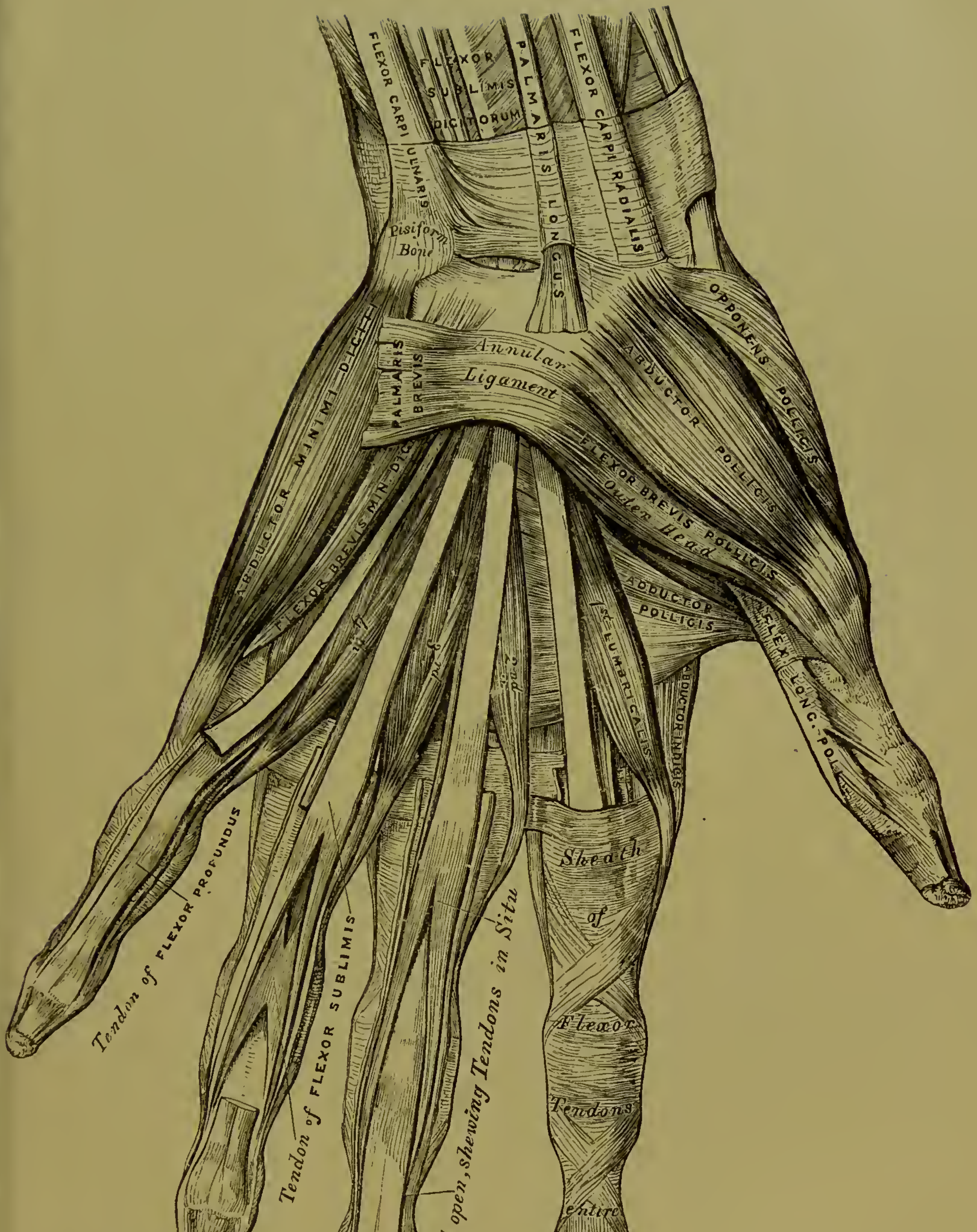

Fig. 60.—Muscles of the left hand. Palmar surface.

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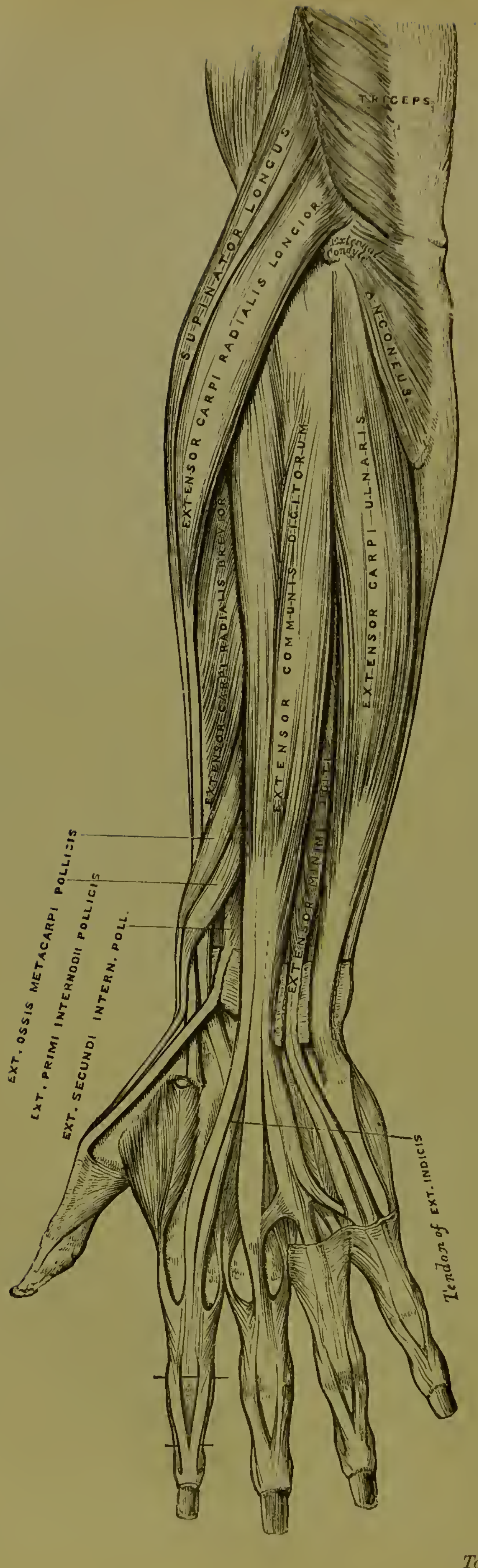

TRICEPS
SUPINATOR LONGUS
EXTENSOR CARPI RADIALIS LONGIOR
External Condyle
ANCONEUS
EXTENSOR CARPI ULNARIS
EXTENSOR COMMUNIS DIGITORUM
EXTENSOR CARPI RADIALIS BREVIOR
EXTENSOR MINIMI DIGITI
EXT. OSSIS METACARPI POLLICIS
EXT. PRIMI INTERNODII POLLICIS
EXT. SECUNDI INTERN. POLL.
Tendon of EXT. INDICIS

Fig. 61.—Posterior surface of forearm. Superficial muscles.

To face page 111.

to be inserted into either side of the first phalanges of every finger: these serve, when acting separately, to move the fingers from side to side; when acting together, they steady the phalanx, so that the others can move surely on it in extension (Fig. 60).

The upper extremity is covered by a tendinous expansion or fascia which envelops the whole arm, encloses its muscles as in a sheath, and affords them, in their strong actions, "that kind of support which workmen feel in binding their arms with thongs." This fascia likewise descends between many of the muscles, forming strong partitions between them, and affording points of origin to many of their fibres, scarcely less fixed than bone itself.

From the whole, it appears that the first joint of the upper extremities, that of the shoulder, is a ball and socket joint, a joint admitting of motion in every direction; that the second joint, that of the elbow, is partly a hinge-joint; admitting of flexion and extension, and partly a rotation joint, admitting of a turning or rotary motion; and that the joints of the wrist and of the fingers are likewise hinge-joints, admitting at the same time of some degree of lateral motion. When these various motions are combined, the result is that the hand can apply itself to bodies in almost every direction, in any part of the area described by the arm, when all the joints are moved to their utmost extent. There is thus formed an instrument of considerable strength, capable of a surprising variety and complexity of movements, capable of seizing, holding, pulling, pushing, and striking with great power, yet at the same time capable of apprehending the minutest objects, and of guiding them with the utmost gentleness, precision, and accuracy, so that there are few conceptions of the designing mind which cannot be executed by the skilful hand.

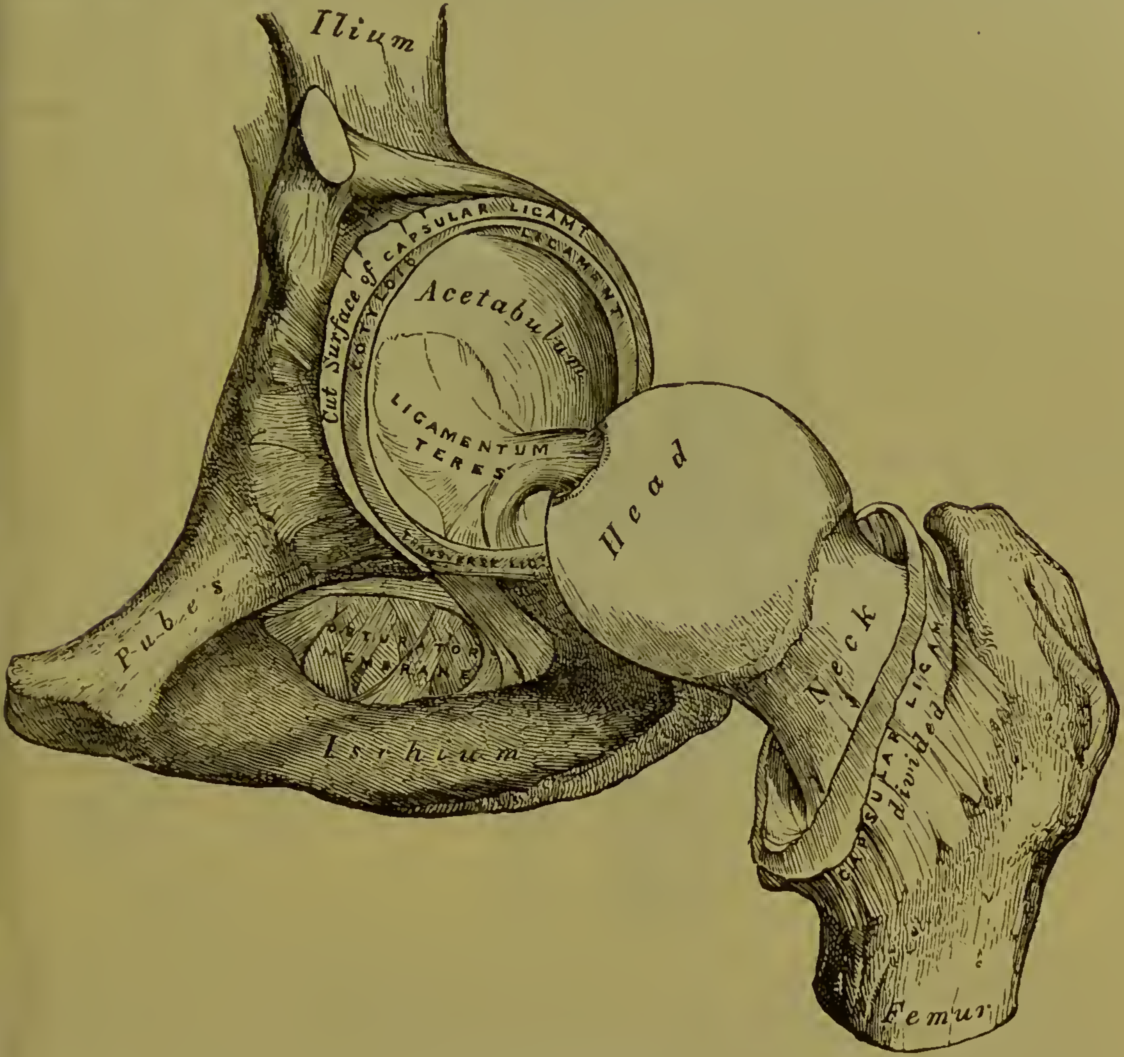
The lower extremities consist of the thigh, leg, and foot.

The osseous part of the thigh consists of a single bone, called the femur (Fig. 31), the longest, thickest, and strongest bone in the body. It sustains the entire weight of the trunk, and occasionally much heavier loads superimposed upon it. It is constructed in such a manner as to combine strength with lightness. This is effected by rendering the bone what is technically called cylindrical; that is, a bone in which the osseous fibres are arranged around a hollow cylinder. There are two varieties of osseous matter (Chap. vi.)—the compact, in which the fibres are dense and solid, and the spongy, in which the fibres are comparatively tender and delicate. Both varieties are, indeed, combined, more or less, in every bone, the compact substance being always external, and the spongy internal; but in the cylindrical bones the arrangement is peculiar. Every long or cylindrical bone consists of a body or shaft, and of two extremities. The body is composed principally of compact substance, which, on the external surface, is so dense and solid, that scarcely any distinct arrangement is visible; but towards the interior this density diminishes; the fibres become distinct, and form an expanded tissue of a cellular appearance, the cells being called cancelli, and the structure cancellated. In the centre of the bone even the cancelli disappear, and a hollow space is left, filled up by the marrow. In the body of the bone, to which strength is requisite, that part being the most exposed to external violence, the compact matter is arranged around a central cavity. By this means strength is secured without any addition of weight; for the resisting power of a cylindrical body increases in proportion to its diameter; consequently the same number of osseous fibres placed around the circumference of a circle produce a stronger bone than could have been constructed had the fibres been consolidated in the centre, and had the diameter been proportionally diminished. The hollow space thus gained in its centre renders the bone lighter, while its strength is not only not diminished by this arrangement, but positively increased. On the other hand, at the extremities of the bone, space, not strength, is required; required for the attachment and arrangement of the tendons of the muscles that act upon it, and for the formation of joints. Accordingly, at its extremities the bone swells out into bulky surfaces; but these surfaces are composed, not of dense and solid substance, but of spongy tissue, of whose fibres those which are in the direction of greater pressure are always stronger than the rest, as instanced in the diagram (Fig. 63); covered by an exceedingly thin crust of compact matter, and so, as by the former expedient strength is secured without increase of weight, by this, space is obtained without increase of weight.

The thigh-bone, placed at the under and outer part of the pelvis, has an oblique direction, the under being considerably nearer its fellow than the upper end (Fig. 31), in order to afford space for the passages at the bottom of the pelvis, and also to favour the action of walking. The body of the bone, which is of a rounded form, is smooth on its anterior surface, where it is always slightly convex, the convexity being forwards, while its posterior surface is irregular and rough, and forms a sharp prominent line, termed the linea aspera, giving attachment to numerous muscles.

The superior extremity of the femur terminates in a large ball or head, which forms nearly two-thirds of a sphere (Fig. 62). It is smooth, covered with cartilage, and received into the socket of the ilium called the acetabulum, which, deep as it is, is still further deepened by the cartilage which borders the brim (Fig. 62). The brim is particularly high in the upper and outer part, because it is in this direction that the reaction of the ground against the descending weight of the trunk tends to dislodge the ball from its socket.

Fig. 62.



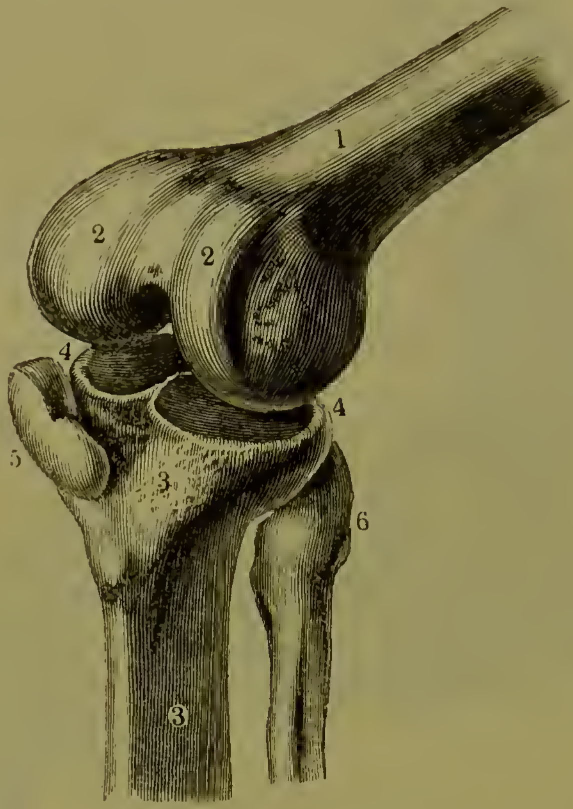
Left hip-joint laid open.

Passing obliquely downwards and outwards from the ball, is that part of the femur which is called the neck (Fig. 62). It spreads out archlike between the head and body of the bone, and is more than an inch in length. It is thus long, in order that the head of the bone may be set deep in its socket, and that its motions may be wide, free, and unembarrassed.

From the external surface of the femur, nearly in a line with its axis, at the root of its neck proceeds upwards the largest and strongest bony process of the body, which gives insertion to its most powerful muscles, namely, those that extend the thigh and that turn it upon its axis (Fig. 31); because, from its oblique direction, it rotates the thigh; this process is called the trochanter, and from its size, the trochanter major. At the under and inner part of the neck on the posterior surface of the bone, is a similar process, but much smaller, called the trochanter minor, into which are inserted the muscles that bend the thigh.

The inferior extremity of the femur, much broader and thicker than the superior (Fig. 63, 1), is terminated by two eminences, with smooth

Fig. 63.



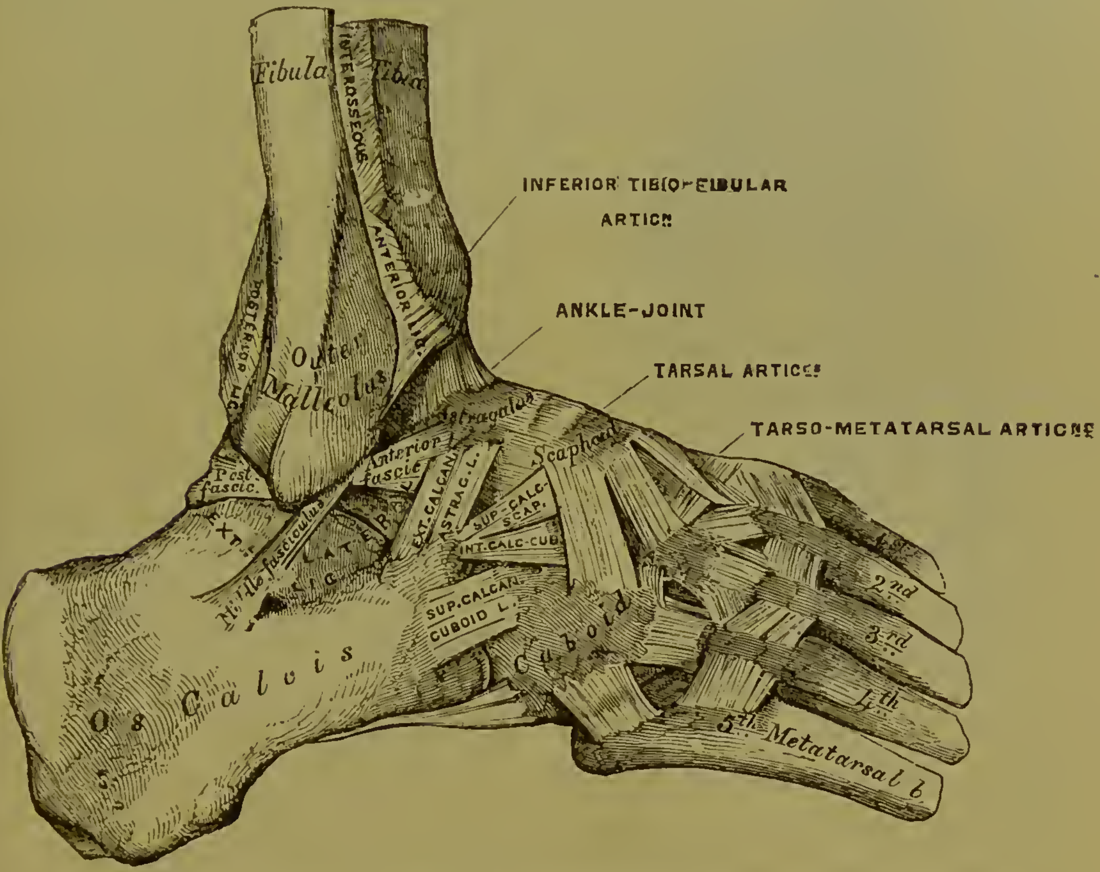
1, lower end of the femur; 2, condyles of the femur; 3, upper end of the tibia; 4, articular surfaces on the head of the tibia on which the thigh-bone plays; 5, the patella, or knee-pan; 6, upper end of the fibula, not entering into the knee-joint.

surfaces, termed condyles (Fig. 63, 2), which, articulated with the tibia, and the patella, form the joint of the knee (Fig. 63, 2, 4, 5).

The bones of the leg, two in number, consist of the tibia (Fig. 31) and fibula. The tibia, next to the femur, the longest bone in the body, is situated at the inner side of the leg. Its superior extremity is bulky and thick The top of it forms two smooth and slightly concave surfaces, adapted to the convex surfaces of the condyles of the femur (Fig. 63, 4, 2). On its outer side there is a smooth surface, to which the head of the fibula is attached (Fig. 63, 6). Its lower extremity, which is small, forms a concavity adapted to the convexity of the bone of the tarsus, called the astragalus, with which it is articulated (Fig. 64). Its inner part is produced so as to form the inner ankle; its outer side is excavated into a semilunar cavity, for receiving the under end of the fibula, which forms the outer ankle (Fig. 64).

The fibula, in proportion to its length the most slender bone of the body, is situated at the outer side of the tibia (Fig. 31). Its upper end, formed into a head, with a flat surface on its inner side (Fig. 63), is firmly united to the tibia. Its lower end forms the outer ankle, which is lower and farther back than the inner (Fig. 64).

Fig. 64.



Ankle-joint: tarsal and tarso-metatarsal articulations. External view, right side.

The patella, or knee-pan (Figs. 31 and 63), is a light but strong bone, of the figure of the heart as painted on playing-cards, placed at the fore part of the joint of the knee, and attached by a strong ligament to the tibia, the motions of which it follows. It is lodged, when the knee is extended, in a cavity formed for it in the femur (Fig. 63); when bent, in a cavity formed for it at the fore-part of the knee (Fig. 63, 5).

The foot consists of the tarsus, metatarsus, and toes.

The tarsus, or instep, is composed of seven strong, irregular-shaped bones, disposed like those of the carpus, in a double row (Fig. 64). The arrangement of the tarsal bones is such as to form an arch, the convexity of which above, constitutes the upper surface of the instep (Fig. 64): in the concavity below are lodged the muscles, vessels, and nerves that belong to the sole.

The metatarsus consists of five bones, which are placed parallel to each other (Fig. 64), and which extend between the tarsus and the proper bones of the toes (Fig. 64). Their extremities, especially next the tarsus, are large, in order that they may form secure articulations with the tarsal bones. Their bodies are arched upwards, slightly concave below, and terminate forwards in small, neat, round heads, which receive the first bones of the toes, and with which they form joints, admitting of a much greater degree of rotation than is ever exercised in civilized life, in consequence of the practice of wearing shoes. The natural, free, wide-spreading form of the toes, and the consequent security with which they grasp the ground, is greatly impaired by this custom.

Each toe consists of three distinct bones, called, like those of the fingers, phalanges (Fig. 31), but the great toe, like the thumb, has only two. That extremity of the first phalanges, which is next the metatarsal bones, is hollowed into a socket for the head of the metatarsal bones.

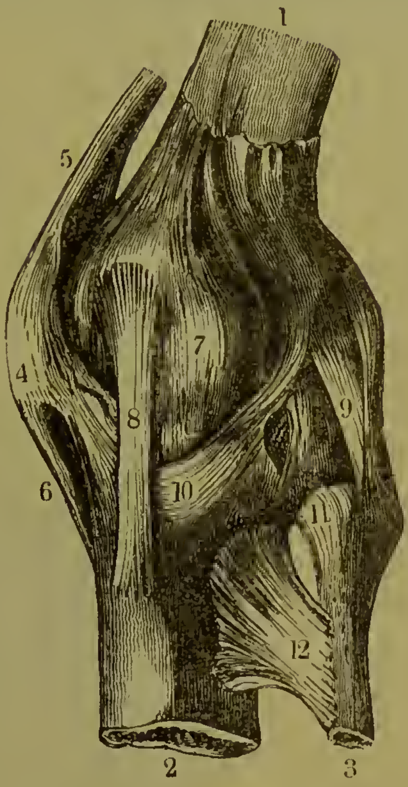
Besides the bones already described, there are other small bones, of the size and figure of flattened peas, found in certain parts of the extremities, never in the trunk, called sesamoid, from their resemblance to the seed of the sesamum. They belong rather to the tendons of the muscles than to the bones of the skeleton. They are embedded within the substance of tendons, are found especially at the roots of the thumb and of the great toe, and are always placed in the direction of flexion. Their office, like that of the patella, which is, in truth, a bone of this class, is to increase the power of the flexor muscles by altering the line of their direction, that is, by removing them farther from the axis of the bone on which they are intended to act.

The ligaments which connect the bones of the lower extremities are the firmest and strongest in the body. Of these, the fibrous capsule of the hip-joint (Fig. 62), which secures the head of the femur in the cavity of the acetabulum, is the thickest and strongest. It completely surrounds the joint. It arises from the whole circumference of the acetabulum, and, proceeding in a direction outwards and backwards, is attached below the neck of the femur (Fig. 62). It is thicker, stronger, and much more closely attached to the bones than the fibrous capsule of the shoulder-joint, because the hip-joint is formed, not like the shoulder-joint, for extent of motion, but for strength. Its internal surface is lined by synovial membrane, and its external surface is covered and strengthened by the insertion of muscles that move the thigh-bone. The joint is strengthened by another ligament, which passes from the inner and fore part of the cavity of the acetabulum (Fig. 62, Ligam. Teres), to be inserted into the head of the femur, called the round ligament, the office of which obviously is to hold the head of the femur firmly in its socket.

Numerous and complicated ligaments connect the bones that form the knee-joint (Fig. 65), and the strength of these powerful bands is greatly increased by the tendons that move the leg (Fig. 65, 5), which pass over, and more or less surround, the joint.

Strong ligaments maintain in their proper position the bones that form the ankle-joint (Fig. 64), connect the bones of the tarsus and metatarsus with one another (Fig. 64), and articulate the several phalanges of the toes.

Fig. 65.



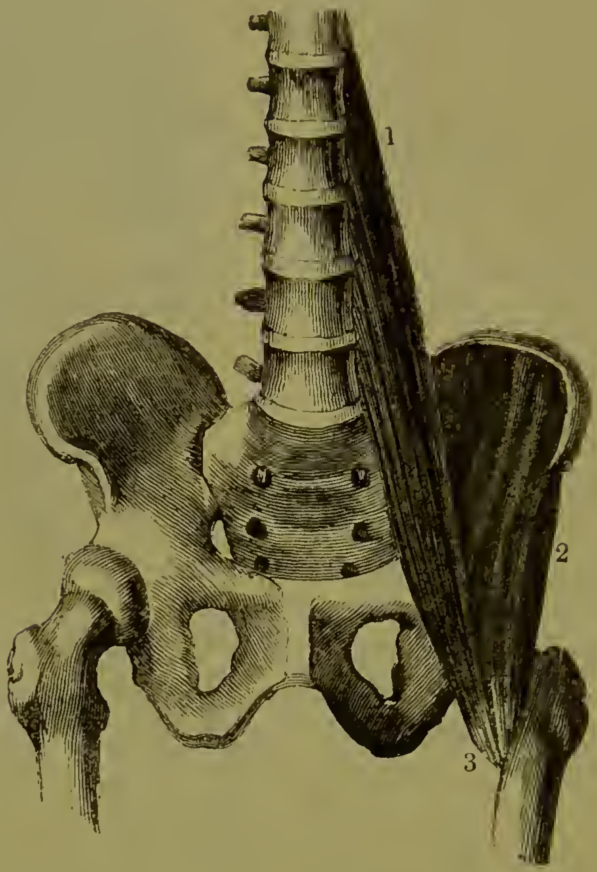
General view of the ligaments of the knee-joint. 1, lower end of the femur; 2, upper end of the tibia; 3, upper end of the fibula; 4, the patella; 5, united tendons of the extensor muscles; 6, ligaments of the patella; 7, the capsular investment of the knee; 8, the internal lateral ligament; 9, the external lateral ligaments; 10, the posterior ligament; 11, the ligament connecting the tibia and fibula; 12, a portion of the interosseous ligament.

The joint of the hip, like that of the shoulder, is capable of flexion, extension, and rotation; but its rotary motions are to a much less extent, on account of the greater depth of the acetabulum, and the stronger and shorter fibrous capsule. When the femur is flexed, the thigh is bent upon the pelvis, and its inferior extremity is carried forwards. When it is extended, the thigh is carried backwards. The two thighs may be separated from each other laterally (abduction), or brought near to each other (adduction), or the one may be made to cross the other, and they may be rotated outwards or inwards.

The apparatus of muscles that produces these varied motions is seated partly on the trunk and partly on the pelvis. Thus, the powerful muscle that flexes the thigh, or that carries it forwards, termed the psoas (Fig. 66, 1), arises from the last vertebra of the back, and successively from each vertebra of the loins, and is inserted into the lesser trochanter of the femur. Its action is assisted first by a large and strong muscle named the iliacus (Fig. 66, 2), which occupies the whole concavity of the ilium, and which, like the psoas, is inserted into the lesser trochanter of the femur (Fig. 66, 3).

The muscles that extend the thigh, or that carry it backwards, named the glutæi, the most powerful muscles of the body, are placed in successive layers, one upon the other (Fig. 67, 9), on the back part of the ilium, and are inserted into the linea aspera of the femur. Their powerful action in drawing the thigh backwards is assisted by several other muscles. Their action is never perfectly simple and direct; for those which move the thigh forwards sometimes carry it inwards, and sometimes outwards; and, in like manner, those which move it backwards, at one time carry it inwards and at another outwards, according to the direction of the fibres of the muscle and the position of the limb when those fibres act; while some of them, and more especially those which carry it backwards, at the same time rotate it, or roll it upon its axis.

Fig. 66.

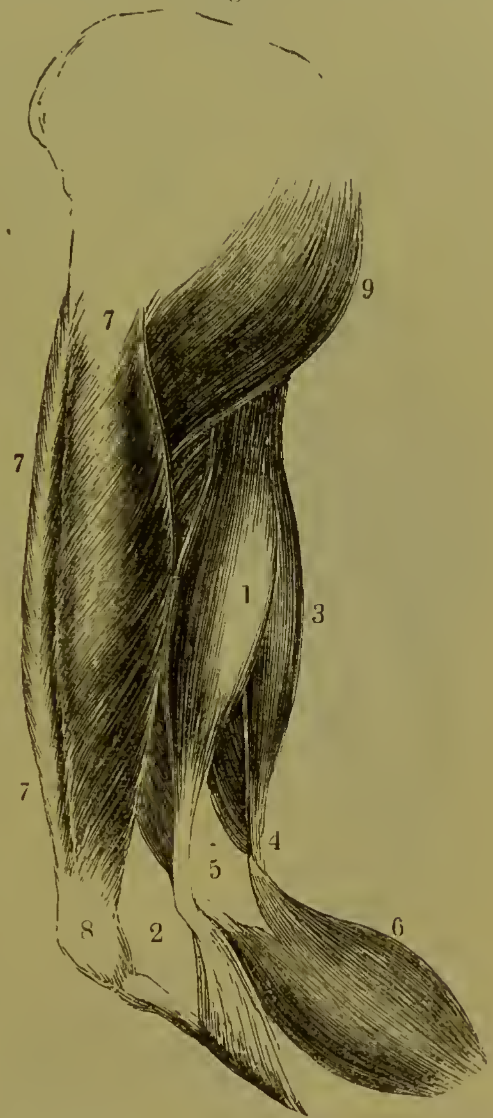


View of the muscles that bend the thigh. 1, the muscle called psoas; 2, the muscle called iliacus; 3, tendons of these muscles, going to be inserted into the trochanter minor of the femur.

The knee is a hinge-joint, admitting only of flexion and extension, and is, therefore, provided only with two sets of muscles, one for bending and the other for extending the leg. The flexors of the leg arise from the under and back part of the pelvis, are seated on the back part of the thigh, and are inserted into the upper part either of the tibia or of the fibula (Fig. 67). They consist for the most part of three muscles, named the semi-tendinosus, the semi-membranosus (Fig. 67, 3), and the biceps of the leg (Fig. 67, 1). The tendons of the two former muscles, in passing to be inserted into the leg, form the inner, and that of the latter the outer, hamstrings (Fig. 67, 4, 5).

Four large muscles, blended together in such a manner as to form one muscle of prodigious size, termed the quadriceps cruris (Fig. 67, 7), occupying nearly all the fore part and the sides, and a considerable portion of the back part of the thigh, constitute the great flexor of the thigh. This enormous mass of muscle arises partly from the ischium and partly from the upper part of the femur (Fig. 67, 7), and is all inserted into the patella (Fig 67, 8), which constitutes a pulley for the purpose of assisting the action of these powerful muscles.

Fig. 67.



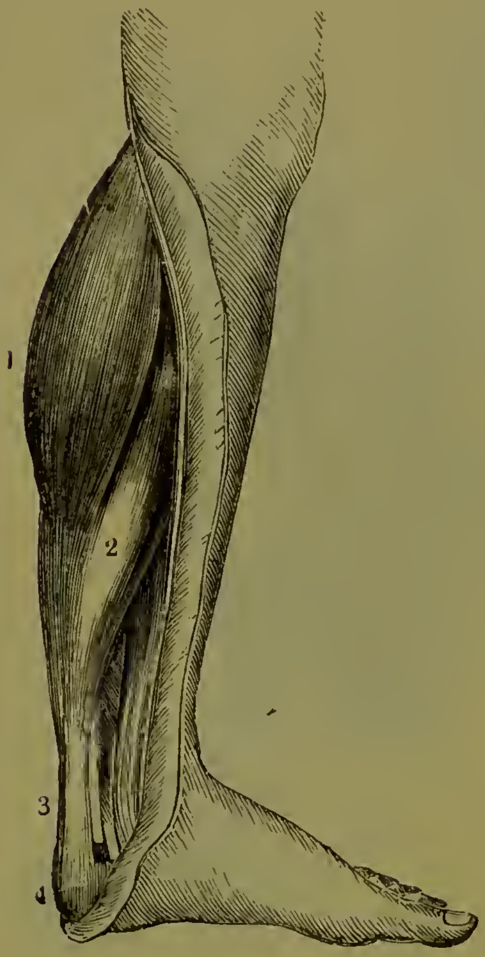
View of the flexor and extensor muscles of the leg. 1, the biceps of the leg; 2, tendon of the biceps, inserted into the head of the fibula; 3, the semi-membranosus, passing to be inserted into the head of the fibula; 4, tendon of the semi-membranosus forming the inner, and 5, tendon of the biceps forming the outer, hamstring; 6, upper part of the gastrocnemius muscle; 7, the four large muscles which unite to form the great extensor muscle of the leg, inserted into 8, the patella; 9, a portion of the glutæus maximus concealing the other muscles of the hip.

The muscles which bend the toes and extend the foot, termed the gastrocnemii (Fig. 68, 1, 2), are placed on the back part of the leg, and form the mass of muscle which constitutes the calf of the leg (Fig. 68, 1, 2). They arise partly from the lower extremity of the femur and partly from the upper and back part of the fibula and tibia; and they form the largest and strongest tendon in the body, termed the tendo achillis (Fig. 68, 3), which is implanted into the heel.

The muscles which extend the toes and bend the foot are seated on the fore-part of the leg; split into tendons like the analogous muscles of the fingers, and are bound down by a ligament, exactly the same in name, disposition, and office, as that which belongs to the hand. Numerous minute muscles are placed in the sole of the foot, which act on the toes as the small muscles in the palm of the hand act on the fingers.

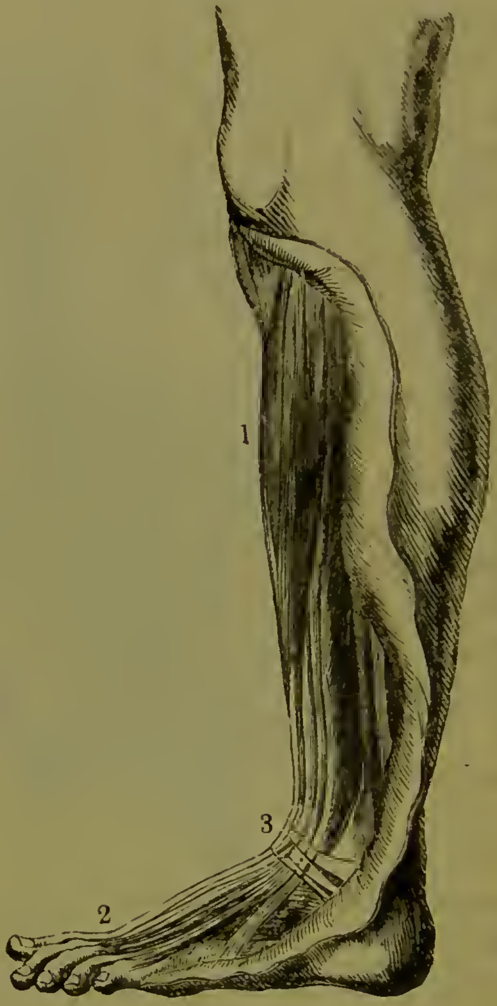
Such are the moving powers which put in action the complicated mechanism provided for the function of locomotion. And these powers are adequate to their office: but they are what may be termed expensive powers; agents requiring a high degree of organization and the utmost resources of the economy to support and maintain them. Hence, in the construction of the frame-work of the machine which they have to move, whatever mechanical contrivance may economize their labour, is adopted. The construction, form, and disposition of the several parts of that frame-work have all reference to two objects: first, the combination of strength with lightness; and, secondly, security to tender organs, with the power of executing rapid, energetic, and, sometimes, violent motions. The combination is effected and the object attained in a mode complicated in the detail, simple in the design, and perfect in the result. The weight of the body transmitted from the arch of the pelvis to a second arch, formed by the neck of the thigh-bone, and from this, in a perpendicular direction, to a third arch formed by the foot, is ultimately received by the heel behind, and by the metatarsal bones and the first phalanges of the toes before, and more especially by the metatarsal joints belonging to the great and little toes, which have a special apparatus of muscles, for the purpose

Fig. 68.



View of the muscles which bend the toes, and which, by lifting the heel, extend the foot. 1, the muscle called gastrocnemius externus, which, uniting with 2, the gastrocnemius internus, forms 3, the tendo achillis, which is inserted into 4, the heel.

Fig. 69.



View of the muscles which extend the toes and bend the foot. 1, the common extensor; 2, the tendons of the same muscle inserted into the toes; 3, the anterior annular ligament of the foot.

of preserving steadily their relative situation to the heel. The weight of the body is thus sustained on a series of arches, from which it is, in succession, transmitted to the ground, where it ultimately rests upon a tripod: forms known and selected as the best adapted to afford support, and to give security of position. Columns of compact bone superimposed one upon another, and united at different points by bands of prodigious strength, form the pillars of support. But these bony columns never touch each other; are never in actual contact; are all separated by layers of elastic matter which, while they assist in binding the columns together, enable them to move one upon another, as upon so many pliant springs. The layers of cartilage interposed between the several vertebræ; the layer of cartilage interposed between the vertebral column and the pelvis; the layer of cartilage that lines the acetabulum and that covers the head of the femur; the layer of cartilage that covers the lower extremity of the femur and the upper extremity of the tibia and fibula and the tarsus; the successive layers of cartilage interposed between the several bones of the tarsus; and, finally, the layer of cartilage that covers both the tarsal and the digital extremities of the metatarsal bones; are so many special provisions to prevent the weight of the body from being transmitted to the ground with a shock; and, at the same time, so many barriers established between the ground and the spinal cord, the brain and the soft and tender organs contained in the thoracic and abdominal cavities, to prevent these organs from being injured by the reaction of the ground upon the body. The excellence of this mechanism is seen in its results; in contemplating "from what heights we can leap—to what heights we can spring—to what distances we can bound—how swiftly we can run—how firmly we can stand—how nimbly we can dance—and yet how perfectly we can balance ourselves upon the smallest surfaces of support!"

It is necessary, in order to complete this general view of the structure of the human body, and of the combination and arrangement of its various parts, to denote the several regions into which, for the purpose of describing with accuracy the situation and relation of its more important organs, the body is divided. It is not needful to the present purpose to describe the regions of the head, because its internal cavity contains only one organ, the brain, and its external divisions do not differ materially from those which are common and familiar; but the abdomen is mapped out into regions, of which it is very important to have an exact knowledge, which may be acquired by the study of Fig. 89.

CHAPTER XI.

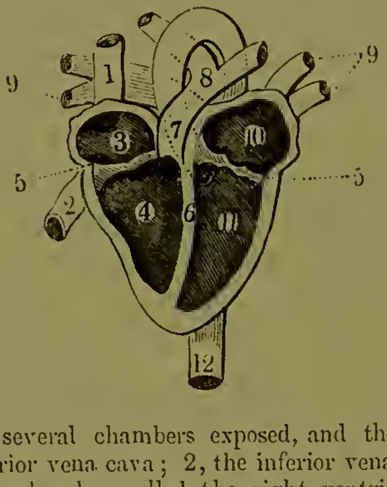
OF THE CIRCULATION.

Vessels connected with the heart: chambers of the heart—Position of the heart—Pulmonic circle: systemic circle—Structure of the heart, artery, and vein—Consequences of the discovery of the circulation to the discoverer—Action of the heart: sounds occasioned by its different movements—Contraction: dilatation—Disposition and action of the valves—Powers that move the blood—Force of the heart—Action of the arterial tubes: the pulse: action of the capillaries: action of the veins—Self-moving power of the blood—Vital endowment of the capillaries: functions—Practical applications.

The blood being necessary to nourish the tissues and to stimulate the organs, must be in motion in order to be borne to them. An apparatus is provided for the purpose of originating an impelling force to put the blood in motion.

The heart is the impelling organ; the great vessels in immediate connection with it are the transmitting organs (Fig. 70, 1, 2). The heart is divided into two sets of chambers, one for the reception of the blood from the different parts of the body (Fig. 70, 3, 10); the other for the communication of the impulse which keeps the blood in motion (Fig. 70, 4, 11). The chamber which receives the blood is termed an auricle (Fig. 70, 3, 10), and is connected with a vessel termed a vein (Fig. 70, 1, 2, 9,); that which communicates impulse

Fig. 70.



View of the heart with its several chambers exposed, and the great vessels in connection with them. 1, the superior vena cava; 2, the inferior vena cava; 3, the chamber called the right auricle; 4, the chamber called the right ventricle; 5, the line marking the passage between the two chambers, and the points of attachment of one margin of the valve; 6, the septum between the two ventricles; 7, the pulmonary artery arising from the right ventricle, and dividing, at 8, into right and left for the corresponding lungs; 9, the four pulmonary veins bringing the blood from the lungs into 10, the left auricle; 11, the left ventricle; 12, the aorta arising from the left ventricle, and passing down behind the heart to distribute blood, by its divisions and subdivisions, to every part of the body.

to the blood is termed a ventricle (Fig. 70, 4, 11), and is connected with a vessel termed an artery (Fig. 70, 7, 12). The vein carries blood to the auricle; the auricle transmits it to the ventricle; the ventricle propels it into the artery; the artery, carrying it out from the ventricle, ultimately sends it again into the vein, the vein returns it to the auricle, the auricle to the ventricle, the ventricle to the artery, and thus the blood is constantly moving in a circle; hence the name of the process, the circulation of the blood.

In nourishing the tissues and stimulating the organs, the blood parts with its nutritive and stimulating constituents, and receives in return some ingredients which can no longer be usefully employed in the economy, and others which are positively injurious. An apparatus is established for its renovation and depuration; this organ is termed the lung (Fig. 47), and to this organ the blood must in like manner be conveyed. Thus the blood moves in a double circle, one from the heart to the body and from the body back to the heart, termed the systemic circle; the other from the heart to the lung and from the lung back to the heart, termed the pulmonic circle. Hence in the human body the heart is double, consisting of two corresponding parts the same in name, in nature, and in office; the one appropriated to the greater, or the systemic, and the other to the lesser, or the pulmonic circulation (Fig. 70).

There is a complete separation between these two portions of the heart formed by a strong muscular partition which prevents any communication between them except through the medium of vessels.

The heart is situated between the two lungs in the lower and forepart of the chest, nearly in the centre, but inclining a little to the left side. Its position is oblique (Fig. 47). Its basis is directed upwards, backwards, and towards the right; its apex is directed downwards, forwards, and towards the left, opposite to the interval between the cartilages of the fifth and sixth ribs (Fig. 47). It is enclosed in a bag termed the pericardium (Fig. 48), which consists of serous membrane. The pericardium is considerably larger than the heart, allowing abundant space for the action of the organ. One part of the pericardium forms a bag around the heart (Fig. 48); the other part is reflected upon the heart, so as to form its external covering, and is continued for a considerable distance upon the great vessels that go to and from the heart in such a manner that this bag, like all the serous membranes, constitutes a shut sac. Both that portion of the pericardium which is reflected upon the heart, and that which forms the internal surface of the bag around it, is moistened during life by a serous fluid. That portion of the pericardium which rests on the diaphragm is so firmly attached to it that it cannot be separated without laceration, and by this attachment, together with the great vessels at its base, the heart is firmly held in its situation, although in the varied movements of the body it is capable of deviating to a slight extent from the exact position here described.

When the interior of the heart is laid open there are brought into view four chambers, two for each circle. Those belonging to the pulmonic circle are on the right, those to the systemic on the left side of the body; hence the terms right and left are applied to these respective parts of the heart.

The veins which carry the blood to the right or the pulmonic chambers are two, one of which brings it from the upper, and the other from the lower parts of the body: the first is called the superior, and the second the inferior vena cava (Figs. 47 and 70). Both pour their blood into the first chamber, termed the right auricle (Fig. 70); from the right auricle the blood passes into the second chamber, denominated the right ventricle; from which springs the artery which carries the blood from the heart to the lung, the pulmonary artery (Fig. 70). This is the pulmonic circle. From the lung the blood is returned to the heart by four veins, termed the pulmonary veins (Fig. 70), which pour the blood into the third chamber of the heart, the left auricle (Fig. 70). From the left auricle it passes into the fourth chamber, the left ventricle (Fig. 70), from which springs the artery which carries out the blood to the system, termed the aorta (Fig. 70). This is the systemic circle. In the system the minute branches of the aorta unite with the minute branches that form the venæ cavæ, which return the blood to the right auricle of the heart, and thus the double circle is completed.

The two chambers called the auricles occupy the basis of the heart. The right auricle is situated at the basis of the right ventricle. It is partly membranous and partly muscular. At its upper and back part is the opening of the vena cava superior, which returns the blood to the heart from the head, neck, and all the upper parts of the body. At its lower part is the opening of the vena cava inferior, which returns the blood from all the lower parts of the body.

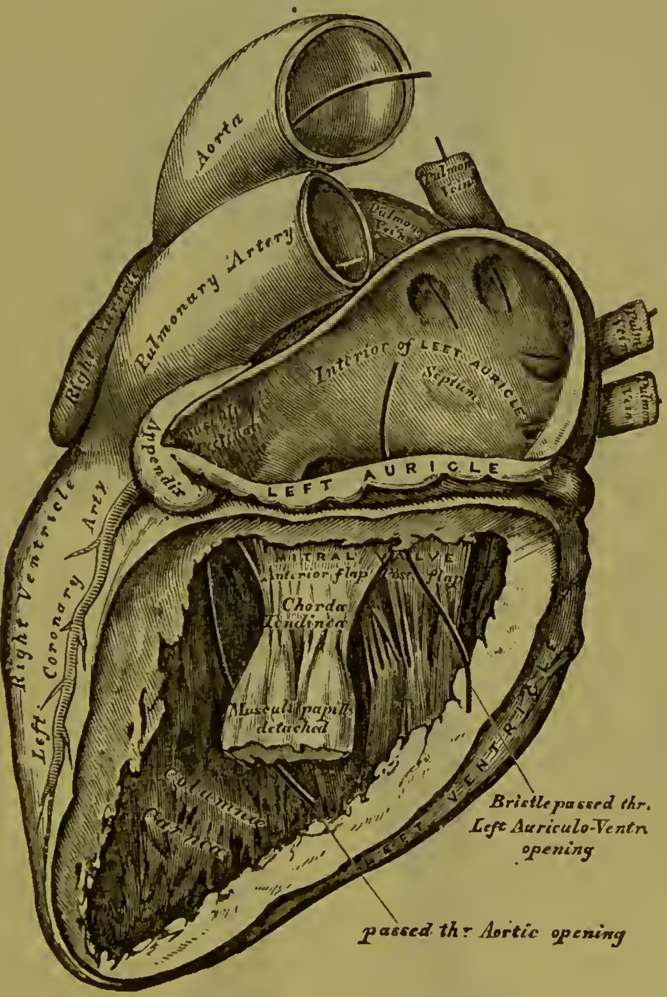
The auricle communicates with its corresponding ventricle by a large opening, termed the auricular orifice of the ventricle. All around the opening is placed a thin but strong membrane (Fig. 48, Tricuspid valve), one margin of which is firmly attached to the wall of the ventricle, while the other is free. This membrane receives the name, and, as will be seen immediately, performs the office of a valve.

The ventricle is much thicker and proportionally stronger than the auricle (Fig. 71). It is composed almost entirely of muscular fibre. Over nearly the whole extent of its internal surface are placed irregular masses of muscular fibres, many of which stand out from the wall of the ventricle like columns or pillars (Fig. 71, musc. papill.), hence they are called fleshy columns (columnæ carneæ). Some of these fleshy columns are adherent by one extremity to the wall of the ventricle, while the other extremity terminates in tendinous threads, which are attached to the membrane that forms the valve.

From the upper and right side of this chamber springs the pulmonary artery (Fig. 71), at the entrance of which are placed three membranes of a crescent or semilunar shape, termed the semilunar valves.

The structure of the left side of the heart is perfectly analogous to that of the right. Its auricle, like that on the left side, is placed at the base of the ventricle (Fig. 71), and like it also is thin, being composed chiefly of membrane. At its upper and back part are the openings of the four pulmonary veins, two from the right, and two from the left lung.

Fig. 71.



The left auricle and ventricle laid open, the anterior walls of both being removed.

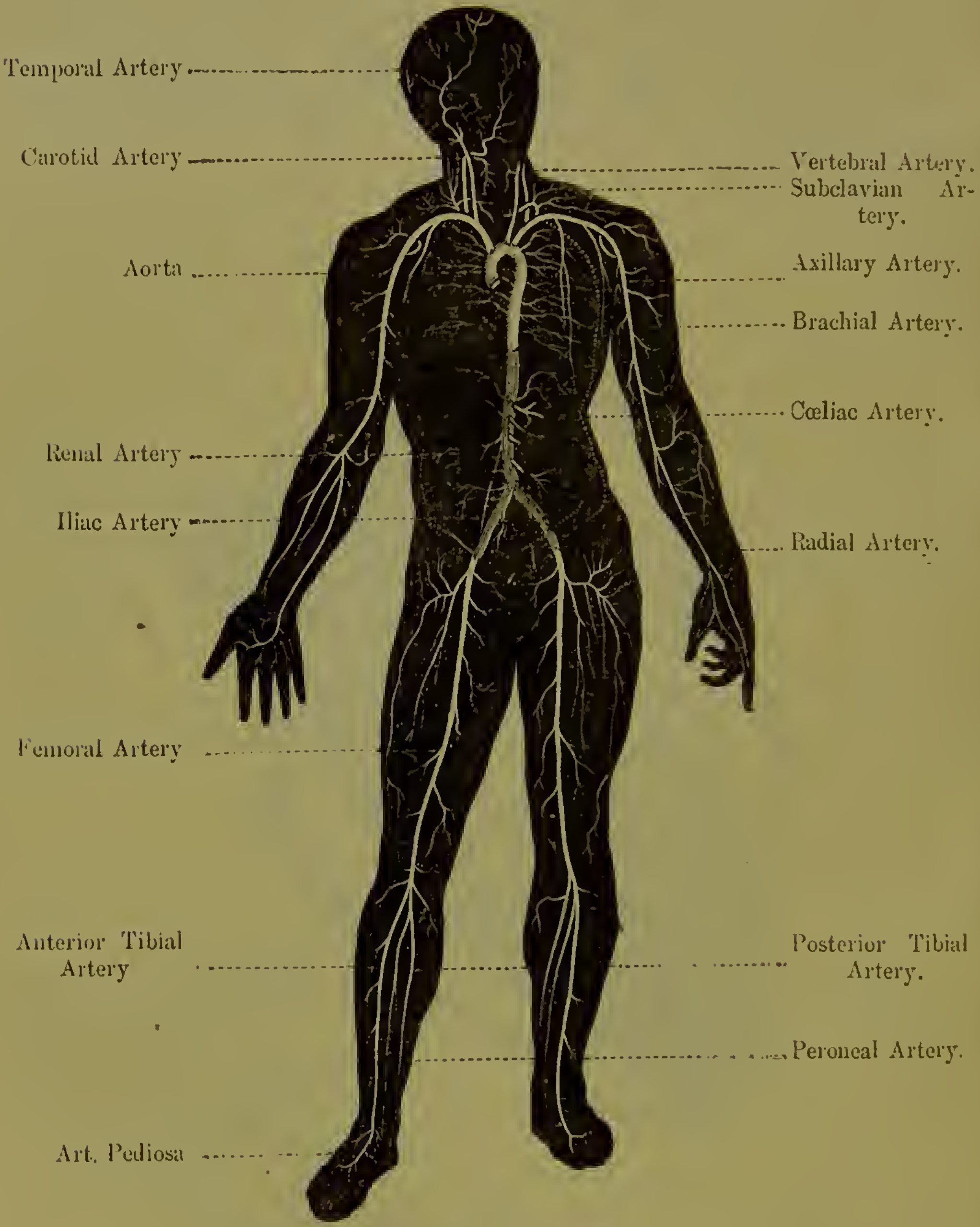
At the passage of communication between the left auricle and ventricle is placed a valve analogous to that on the right side.

The walls of the left ventricle are nearly as thick again as those of the right, and its fleshy columns are much larger and stronger. From the upper and back part of this fourth chamber springs the great systemic artery, the aorta, around the mouth of which are placed three semilunar valves (Fig. 71), similar to those at the mouth of the pulmonary artery.

The partition which divides the two sets of chambers from each other, is wholly composed of muscular fibres, and is called the septum of the heart.

The external surface of the heart is covered by a thin but strong

Fig. 72.



Arterial system in man.

membrane continued over it from the pericardium. Between this membranous covering and its fleshy substance is lodged, even when the body is reduced to the greatest degree of thinness, a quantity of fat. Immediately beneath this fat are the fleshy fibres that compose the main bulk of the organ. These fibres are arranged in a peculiar manner. The arrangement is not perceptible when the heart is examined in its natural state, but after it has been subjected to long-continued boiling, which, besides separating extraneous matters from the fibres, hardens and loosens without displacing them, the manner in which they are disposed is manifest. Just at the point where the muscular fibres that constitute the septum of the auricles are set upon those which form the septum of the ventricles, and parallel with the origin of the aorta, the heart is not muscular but tendinous. The substance called tendon, it has been shown, is often employed in the body to afford origin or insertion to muscular fibres, performing, in fact, the ordinary office of bone, and substituted for it in situations where bone would be inconvenient. From the tendinous matter just indicated most of the fibres that constitute the muscular walls of the heart take their origin. From this point the fibres proceed in different directions: those which go to form the wall of the auricles ascend; those which form the wall of the ventricles pursue an oblique course downwards, and the arrangement of the whole is such, that a general contraction of the fibres must necessarily bring all the parts of the heart towards this central tendinous point. The object, and the result of this arrangement, will be manifest immediately.

The internal surface of the chambers of the heart, in its whole extent, is lined by a fine transparent serous membrane, which renders it smooth and moist; and, like all other organs which have important functions to perform, it is plentifully supplied with blood-vessels and nerves.

Such is the structure of the organ that moves the blood. The artery, the tube that carries it out from the heart, is a vessel composed of three distinct layers of membrane superimposed one upon another, and intimately united by delicate cellular tissue. These layers are termed tunics or coats. The outer coat differs but little from ordinary dense areolar tissue, and is somewhat elastic; it is attached loosely by its outer surface to the sheath, which is provided to surround and enclose the artery and accompanying veins, and by its inner surface is very closely adherent to the next or middle coat. This is the best characterized of the three coats, and consists of fibres disposed chiefly in an encircling manner around the calibre of the vessel.

These fibres are of two sorts, some are yellow elastic fibres, such as were formerly described, and the others are muscular fibres of the plain unstriped sort.

The first of these confers on the arterial walls the property of resiliency, so that after being distended somewhat by the rush of blood forced into them from the heart, the walls of the arteries recoil by their elasticity returning upon the current within them the same amount of force as was employed in their distension.

By this beautiful contrivance, the suddenness and violence of the heart's impulse upon the smaller and weaker vessels is most favourably mitigated, for a moiety of the force of the heart is expended in dilating the greater arteries. This force is not wasted, but returns to reinforce the circulating power just when in the interval between the heart's beats it is most needed. It will be plainly seen that elasticity is required principally in the neighbourhood of the heart; for in proportion as the wave passes on further from the heart, will the suddenness and force of its impulse be brought down through the elasticity of the vessels already traversed, so that when the current arrives at the small arteries, it has become almost uniform, and by the time it reaches the thin-walled and delicate capillaries its flow is even and equable. In accordance with this decrease in the requirement of elasticity, the arteries, as they diminish in size, have in their middle coat a smaller and smaller proportion of elastic fibres; meanwhile, however, the proportion of the muscular fibres of the middle coat increases as the vessel's size lessens, so that the middle coat of small arteries still maintains a substantial thickness. The muscular part of the arterial wall, by its contraction and relaxation, narrows or widens the channel of the vessel, so as to admit a larger or smaller volume of blood into the territory nourished from it.

Such alterations of the calibre of arteries are rendered necessary by the variation in the activity of organs fed through them; for the organs consume blood in proportion as they are active, and they demand blood in proportion as they consume it; so that in its full work an organ will need much more blood than when in repose.

To accommodate the greater flow of blood, the arteries of an active organ dilate through the relaxation of the muscular fibres of the middle coat, and when the organ resumes the quiet state, those fibres contracting close the calibre of the vessel in upon the diminished current. To convey the influence which in this way duly adjusts the size of the vessel to the temporary requirements of its field of distribution, there are little nerves which follow the arteries, and branch into their substance to reach the muscle in their wall: these nerves belong to the sympathetic system.

The inner coat of the artery is thin, and made of elastic membrane, lined in the greater arteries by a covering of epithelium, such as is found where much friction exists; it is tougher than the other coats, so that when the surgeon ties an artery, the tightened string will divide the outer and middle coats, but the inner will resist successfully.

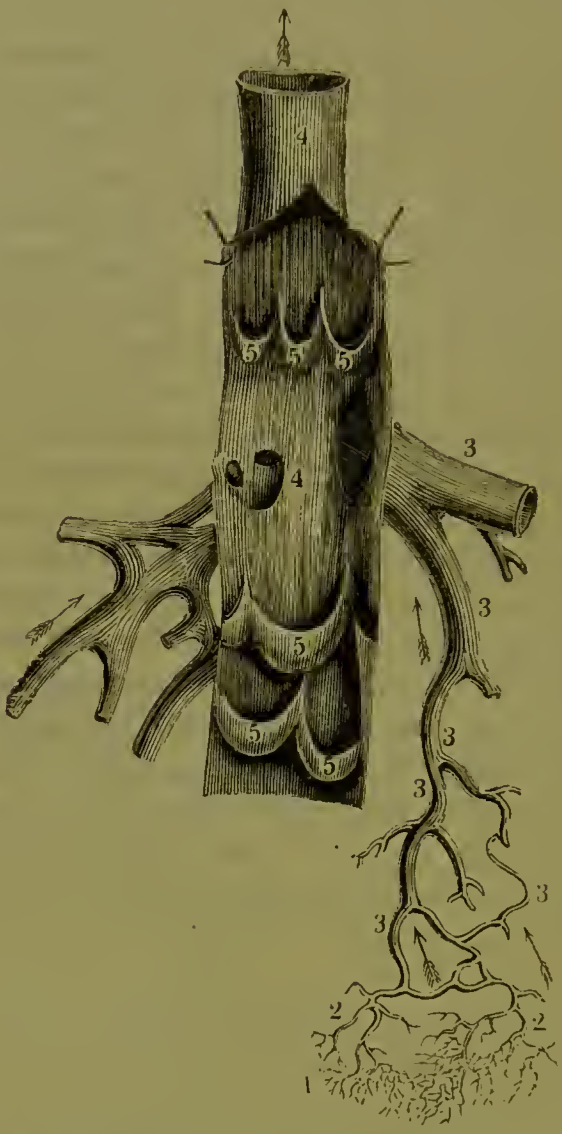
The vein, the tube that carries back the blood to the heart, is composed of the same number of tunics as the artery, which, with the exception of the middle, are essentially the same in structure, but they are all much thinner. The external tunic consists of a less dense and strong cellular membrane; the middle tunic, instead of being formed of elastic rings, is composed of soft and yielding fibres, disposed in a longitudinal direction; while the inner coat, which is still more delicate than that of the artery, is arranged in a peculiar manner. The inner coat of most veins, at slight intervals, is formed into folds (Fig. 73, 5), one margin of which is firmly adherent to the circumference of the vessel, while the other margin is free and turned in the direction of the heart. These membranous folds are termed valves. In all veins, the diameter of which is less than a line, the valves are single; in most veins of greater magnitude they are placed in pairs, while in some of the larger trunks they are triple, and in a few instances quadruple, and even quintuple. The veins, like the arteries, are supplied with nutrient vessels and nerves.

All the arteries of the body proceed from the two trunks already described; that connected with the pulmonic circle, the pulmonary artery, and that connected with the systemic circle, the aorta. These vessels, as they go out from the heart, and proceed to their ultimate termination, are arborescent, that is, they successively increase in number and diminish in size, like the branches of a tree going off from the trunk (Fig. 73). Each trunk usually ends by dividing into two or more branches, the combined area of which is always greater than that of the trunk from which they spring, in the proportion of about one and a half to one. As the branch proceeds to its ultimate termination it divides and subdivides, until at length the vessel becomes so minute, that it can no longer be distinguished by the eye. These ultimate branches are called capillary vessels, from their hair-like smallness; but this term does not adequately express their minuteness.

The disposition of the veins, like that of the arteries, is arborescent, but in an inverse order; for the course of the veins is from capillary vessels to visible branches, and from visible branches to large trunks. In every part of the body where the capillary arteries terminate the capillary veins begin, and the branches uniting to form trunks, and the small to form large trunks, and the trunks always advancing towards the heart, and always increasing in magnitude as they approach it, form at length the two veins which it has been stated return all the blood of the body to the right auricle of the heart.

The veins are very much more numerous than the arteries, for they often consist of double sets, and they are at the same time more capacious and more extensible. Reckoning the whole of the blood at one-fifth of the weight of the body, it is estimated that, of this quantity, about one-fourth is in the arterial and the remaining three-fourths in the venous system. The combined area of the branches of the veins is much greater than that of the two trunks in which they terminate (Fig. 73, 1, 2, 3, 4): the blood, therefore, in returning to the heart, is always flowing from a large into a smaller space.

Fig. 73.



View of the manner in which the minute branches of the vein unite to form the larger branches and the trunks. 1, capillary venous branches; 2, small branches formed by the union of the capillary; 3, larger branches formed by the union of the smaller and gradually increasing in size, to form the great trunk, 4, a portion of which is laid open to show its inner surface, and the arrangement of, 5, the valves formed by its inner coat.

The divisions and subdivisions of the artery freely communicate in all parts of the body by means of what are called anastomosing branches, and this communication of branch with branch and trunk with trunk is termed anastomosis. The same intercommunication, but with still greater freedom and frequency, takes place among the branches of veins. In both orders of vessels the communication is frequent in proportion to the minuteness of the branch and its distance from the heart. It is also more frequent in proportion as a part is exposed to pressure; hence the minute arteries and veins about a joint are distinguished for the multitude of their anastomosing branches; and above all, it is frequent in proportion to the importance of the organ; hence the most remarkable anastomosis in the body is in the brain. By this provision care is taken that no part be deprived of its supply of blood; for if one channel be blocked up, a hundred more are open to the current, and the transmission of it to any particular region or organ by two or more channels, instead of through one trunk, is a part of the same provision. Thus the fore-arm possesses four principal arteries with corresponding veins, and the brain receives its blood through four totally independent canals.*

That the blood is really a flowing stream, and that it pursues the course described, is indubitable. For,

(1.) With the microscope, in the transparent parts of animals, the blood can be seen in motion; and if its course be attentively observed, its route may be clearly traced.

(2.) The membranes termed valves are so placed as to allow of the freest passage to the blood in the circle described, while they either altogether prevent or exceedingly impede its movement in any other direction.

(3.) The effect of a ligature placed around a vein and an artery, and of a puncture made above the ligature in the one vessel and below it in the other, demonstrate both the motion of the blood and the course of it. When a ligature is placed around a vein, that part of the vessel which is most distant from the heart becomes full and turgid on account of the accumulation of blood in it; while the part of the vessel which is between the ligature and the heart becomes empty and flaccid, because it has carried on its contents to the heart, and it can receive no fresh supply from the body. When, on the contrary, a ligature is placed around an artery, that portion of the vessel which lies between the ligature and the heart becomes full and turgid, and the other portion empty and flaccid. This can only be because the contents of the two vessels move in opposite directions,—from the heart to the artery, from the artery to the vein, and from the vein to the heart. At the same time, if the vein be punctured above the ligature, there will be little or no loss of blood; while if it be punctured below the ligature, the blood will continue to flow until the loss of it occasions death, which could not be unless the blood were in motion, nor unless the direction of its course were from the artery to the vein and from the vein to the heart.

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* Whenever there is any interruption to the ordinary flow of the circulating fluids, the powers of the anastomosing circulation are capable of being increased to a surprising extent. The aorta itself has frequently been tied in animals of considerable size without destroying life; in the human body it has also been found obliterated by disease in different parts of its course, in one case as high as the termination of its curvature. In the cure for aneurism the external iliac artery has been tied by Mr. Abernethy with success; the subclavian artery below the clavicle by Mr. Keate; the common carotid by Sir Astley Cooper; the subclavian artery above the clavicle by Mr. Ramsden; the internal iliac artery by Dr. Stevens; the arteria innominata by Dr. Mott, of New York; and lastly, the abdominal aorta itself by Sir A. Cooper. Mr. Grainger tied the abdominal aorta of a dog; when the animal had recovered from that operation, the carotids and the great trunks of the anterior extremities were tied; in this manner the whole course of the circulation was altered. The dog, which was of very large size, survived all these operations, and appeared to enjoy its ordinary health.—Grainger's "General Anatomy," p. 251—253.

(4.) If fluids be injected into the veins or arteries, whether of the dead or of the living body, they readily make their way and fill the vessels, if thrown in the direction stated to be the natural course of the circulation; but they are strongly resisted if forced in the opposite direction.

Such is the description, and with the exception of the first proof, such the evidence of the circulation of the blood in the human body, pretty much as it was given by the discoverer of it, the illustrious Harvey. Before the time of Harvey, a vague and indistinct conception that the blood was not without motion in the body had been formed by several anatomists. It is analogous to the ordinary mode in which the human mind arrives at discovery, that many minds should have an imperfect perception of an unknown truth, before some one mind sees it in its completeness and fully discloses it. Having, about the year 1620, succeeded in completely tracing the circle in which the blood moves, and having at that time collected all the evidence of the fact, with a rare degree of philosophical forbearance, Harvey still spent no less than eight years in re-examining the subject, and in maturing the proof of every point, before he ventured to speak of it in public. The brief tract which at length he published was written with extreme simplicity, clearness, and perspicuity, and has been justly characterized as one of the most admirable examples of a series of arguments deduced from observation and experiment that ever appeared on any subject.

Contemporaries are seldom grateful to discoverers. More than one instance is on record in which a man has injured his fortune and lost his happiness through the elucidation and establishment of a truth which has given him immortality. It may be that there are physical truths yet to be brought to light, to say nothing of new applications of old truths, which, if they could be announced and demonstrated to-day, would be the ruin of the discoverer. It is certain that there are moral truths to be discovered, expounded, and enforced, which, if any man had now penetration enough to see them, and courage enough to express them, would cause him to be regarded by the present generation with horror and detestation. Perhaps, during those eight years of re-examination, the discoverer of the circulation sometimes endeavoured in imagination to trace the effect which the stupendous fact at the knowledge of which he had arrived would have on the progress of his favourite science; and, it may be, the hope and the expectation occasionally arose that the inestimable benefit he was about to confer on his fellow-men would secure to him some portion of their esteem and confidence. What must have been his disappointment when he found, after the publication of his tract, that the little practice he had had as a physician, by degrees fell off. He was too speculative, too theoretical, not practical. Such was the view taken even by his friends. His enemies saw in his tract nothing but indications of a presumptuous mind that dared to call in question the revered authority of the ancients; and some of them saw, moreover, indications of a malignant mind, that conceived and defended doctrines which, if not checked, would undermine the very foundations of morality and religion. When the evidence of the truth became irresistible, then these persons suddenly turned round and said, that it was all known before, and that the sole merit of this vaunted discoverer consisted in having circulated the circulation. The pun was not fatal to the future fame of this truly great man, nor even to the gradual though slow return of the public confidence during his own time; for he lived to attain the summit of reputation.

It is then indubitably established that the whole blood of the body in successive streams is collected and concentrated at the heart. The object of the accumulation of a certain mass of it at this organ is to subject it to the action of a strong muscle, and thereby to determine its transmission with adequate force and precision through the different sets of capillary vessels.

In the accomplishment of this object the heart performs a twofold action; that of contraction and that of dilatation. The auricles contract and thereby diminish their cavities, then dilate and thereby expand them, and the one action alternates with the other. There is the like alternate contraction and dilatation of the ventricles. The first action is termed systole, the second diastole, and both are performed with force.

When the heart is laid open to view in a living animal, and its movements are carefully observed, it is apparent that the two auricles contract together; that the two ventricles contract together; that these motions alternate with each other, and that they proceed in regular succession. The interval between these alternate movements is, however, exceedingly short, and can scarcely be perceived when the heart is acting with full vigour; but it is evident when its action is somewhat languid.

When the ventricles contract, the apex of the heart is drawn upwards, and at the same time raised or tilted forwards. It is during this systole of the ventricles, and in consequence of this result of their action, that the apex of the heart gives that impulse against the walls of the chest which is felt in the natural state between the fifth and sixth ribs, and which just perceptibly precedes the pulse at the wrist.

When the ear is applied to the human chest, over the situation of the heart, a dull and somewhat prolonged sound is heard, which precedes and accompanies the impulse of the heart against the chest. This dull sound is immediately succeeded by a shorter and sharper sound: after this there is a short pause; and then the dull sound and impulse are again renewed. The duller sound and stronger impulse are ascribed to the contraction of the ventricles, and the sharper sound and feebler impulse to that of the auricles.

The movement of the heart is effected by the contraction of its muscular fibres. Those fibres rest, as upon a firm support, on the tendinous matter to which they are attached, from which they diverge, and towards which their contraction must necessarily bring all the parts of the heart. The result of their contraction is the powerful compression of all the chambers of the heart, and thereby the forcible ejection of their contents through the natural openings.

But the chambers, alternately with forcible contraction, perform the action of forcible dilatation. This movement of dilatation is effected by the reaction of the elasticity of the tendinous matter on which the muscular fibres are supported. This highly elastic substance, by the contraction of the fibres, is brought into a state of extreme tension. The contraction of the fibres ceasing, that moment the tense tendon recoils with a force exactly proportionate to the degree of tension into which it had been brought. Thus the very agent that is employed forcibly to close the chamber, is made the main instrument of securing its instantaneous reopening. A vital energy is appointed to accomplish what is indispensable, and what nothing else can effect, the origination of a motive power; a physical agent is conjoined to perform the easier task to which it is competent; and the two powers, the vital and the physical, work in harmony, each acting alternately, and each, with undeviating regularity and unfailing energy, fulfilling its appropriate office.

When the chambers of the heart which open into each other, and which as freely communicate with the great vessels that enter and proceed from them, are forcibly closed, and the blood they contain is projected from them, how is one uniform forward direction given to the current? Why, when the right ventricle contracts, is the blood not sent back into the right auricle, as well as forward into the pulmonary artery? There is but one mode of preventing such an event, which is to place a flood-gate between the two chambers; and there a flood-gate is placed, and that flood-gate is the valve. As long as the blood proceeds onwards in the direct course of the circulation, it presses this membrane close to the side of the heart, and thereby prevents it from occasioning any impediment to the current. When, on the contrary, the blood is forced backwards, and attempts to re-enter the auricle, being of course driven in all directions, some of it passes between the wall of the ventricle and the valve. The moment it is in this situation, it raises up the valve, carries it over the mouth of the passage, and shuts up the channel. There cannot be a more perfect flood-gate.

This is beautiful mechanism; but there is another arrangement which surpasses mere mechanism, however beautiful. It has been shown that one edge of the membrane that forms the valve is firmly adherent to the wall of the ventricle, while the other edge, when not in action, appears to lie loosely in the ventricle. Were this edge really loose the refluent current would carry it back completely into the auricle, and so counteract its action as a valve; but it is attached to the tendinous threads proceeding from the fleshy columns that stand along the wall of the ventricle (Fig. 71). By these tendinous threads, as by so many strings, the membrane is firmly held in its proper position; and the refluent current cannot carry it into the auricle. Thus far the arrangement is mechanical. But each of these fleshy columns is a muscle, exerting a proper muscular action. Among the stimulants which excite the contractility of the muscular fibre, one of the most powerful is distension. The refluent current distends the membrane; the distension of the membrane stretches the tendinous threads attached to it; the stretching of its tendinous threads stretches the fleshy column; by this distension of the column it is excited to contraction; by the contraction of the column its thread is shortened; by the shortening of the thread the valve is tightened, and that in the exact degree in which the thread is shortened. So, the greater the impetus of the refluent blood, the greater the distension of the membrane; and the greater the distension of the membrane, the greater the excitement of the fleshy column; the greater the energy with which it is stimulated to act, the greater, therefore, the security that the valve will be held just in the position that is required, with exactly the force that is needed. Here, then, is a flood-gate not only well constructed as far as regards the mechanical arrangement, but so endowed as to be able to act with additional force whenever additional force is requisite; to put forth on every occasion, as the occasion arises, just the degree of strength required, and no more.

The contraction of the heart is the power that moves the blood; and this contraction generates a force which is adequate to impel it through the circle. From experiments performed by Dr. Hales, it appears that if the artery of a large animal, such as the horse, be made to communicate with an upright tube, the blood will ascend in the tube to the height of about ten feet above the level of the heart, and will afterwards continue there rising and falling a few inches with each pulsation of the heart. In this animal, then, the heart acts with a force capable of maintaining a column of ten feet. Now a column of ten feet indicates a pressure of about four pounds and a half in a square inch of surface. Suppose the human heart to be capable of supporting a column of blood eight feet high, this will indicate a pressure of four pounds to the square inch; but the left ventricle of the heart, while it injects its column of blood into the aorta, has to overcome the inertia of the quantity of blood projected; of the mass already in the artery, and of the elasticity of the vessel yielding to a momentary increase of pressure: it is probable, therefore, that the heart acts with a force of six pounds on the inch. The left ventricle, when distended, has about ten square inches of internal surface; consequently the whole force exerted by it may be about sixty pounds. According to the calculation of Hales, it is fifty-one and a half. Now, it is proved by numerous experiments, that, after death, a slight impulse with the syringe, certainly much less than that which is acting upon the blood in the same artery during life, is sufficient to propel a solution of indigo, or fresh-drawn blood, from a large artery into the extreme capillary. If, therefore, after death, a slight force will fill the capillaries, a force during life equal to sixty pounds must be adequate to do so.[3]

The heart, with a force equal to the pressure of sixty pounds, propels into the artery two ounces of blood at every contraction. It contracts four thousand times in an hour. There passes through the heart, therefore, every hour, eight thousand ounces or seven hundred pounds of blood. It has been stated that the whole mass of blood in an adult is about twenty-eight pounds: on an average the entire circulation is completed in two minutes and a half; consequently a quantity of blood equal to the whole mass passes through the heart from twenty to twenty-four times in an hour. But though the average space of time requisite to accomplish a complete circulation may be two minutes and a half, yet when a stream of blood leaves the heart, different portions of it must finish their circle at very different periods, depending in part upon the length of the course which they have to go, and in part upon the degree of resistance that obstructs their passage. A part of the stream, it is obvious, finishes its course in circulating through the heart itself; another portion takes a longer circuit through the chest; another extends the circle round the head; and another visits the part placed at the remotest distance from the central moving power. Such is the velocity with which the current sometimes goes, that, in the horse, a fluid injected into the great vein of the neck, on one side, has been detected in the vein on the opposite side, and even in the vein of the foot, within half a minute.

It has been shown that the different chambers of the heart have a tendency to perform their movements in a uniform manner, and in a successive order; that they contract and dilate in regular alternation, and at equal intervals; but, moreover, they continue these movements equally without rest and without fatigue. On go the motions, night and day, for eighty years together, at the rate of a hundred thousand strokes every twenty-four hours, alike without disorder, cessation, or weariness. The muscles of the arm tire after an hour's exertion, are exhausted after a day's labour, and can by no effort be made to work beyond a certain period. There is no appreciable difference between the muscular substance of the heart and that of the arm. It is true that the heart is placed under one condition which is peculiar. Muscles contract on the application of stimuli; and different muscles are obedient to different stimuli,—the voluntary muscles to the stimulus of volition, and the heart to that of the blood. The exertion of volition is not constant, but occasional; the muscle acts only when it is excited by the application of its stimulus: hence the voluntary muscle has considerable intervals of rest. The blood, on the contrary, is conveyed to the heart without ceasing, in a determinate manner, in a successive order; and this is the reason why through life its action is uniform: it uniformly receives a due supply of its appropriate stimulus. But why it is unwearied, why it never requires rest, we do not know. We know the necessities of the system which render it indispensable that it should be capable of untiring action, for we know that the first hour of its repose would be the last of life; but of the mode in which this wonderful endowment is communicated, or of the relations upon which it is dependent, we are wholly ignorant.

The force exerted by the heart is vital. In the best-constructed machinery there is no real generation of power. There is merely concentration and direction of it. In the recoil of the spring, in the reaction of condensed steam, the energy of the expansive impulse is never greater than the force employed to compress or condense, and the moment this power is expended all capacity of motion is at an end. But the heart produces a force equal to the pressure of sixty pounds by the gentlest application of a bland fluid. Here no force is communicated to be again given out, as in every mechanical moving power; but it is new power, power really and properly generated; and this power is the result of vital action, and is never in any case the result of action that is not vital.

The heart projects the blood with a given force into the arterial tubes. The arteries in the living body aro always filled to distension by the quantity of blood that is in them. It has been shown that the elasticity of their coats is such as to give to them, even after death, the form of open hollow cylinders. By virtue of their elasticity they react upon their contents with a force exactly proportioned to the degree of their distension, that is, with a force at least adequate to keep them always open and rigid.

These open tubes, already filled to distension, and somewhat beyond it, receive at every contraction of the heart a forcible injection of a new wave of blood. The first effect of the injection of this new wave into a tube previously full to distension, is to cause the current to proceed by jerks or jets, each jerk or jet corresponding to the contraction of the heart. And, accordingly, by this jet-like motion, the flow of the blood in the artery is distinguished from that in the vein, in which latter vessel the current is an equal and tranquil stream.

The second effect of this new wave is to occasion some further distension of the already distended artery, and accordingly, when the vessel is exposed in a living animal, and its action carefully observed, a slight augmentation of its diameter is distinguishable at every contraction of the heart. This new wave while it distends must at the same time slightly elongate the vessel; cause its straight portions to bend a little, and its curved portions to bend still more; and consequently, in some situations, to lift it a little from its place, giving it a slight degree of locomotion;—and these two causes combined produce the pulse. When the finger is pressed gently on an artery, at the instant of the contraction of the heart, the vessel is felt to bound against the finger with a certain degree of force: this, as just stated, is owing to a slight distension of the vessel by the new wave of blood, together with a slight elongation of it, and a gentle rising from its situation.

The blood, in flowing through the arterial trunks and branches to the capillaries, through the arterial to the venous capillaries, and through the venous branches and trunks back to the heart, is exposed to numerous and powerful causes of retardation: such, for example, as the friction between the blood and the sides of the vessels, the numerous curves and angles formed by the branches in springing from the trunks, the tortuous course of the vessels in many parts of the body, and the increasing area of the arterial branches as they multiply and subdivide. Yet the extraordinary fact has been recently discovered, that the blood moves with the same momentum or force in every part of the arterial system, in the aorta, in the artery in the neck which carries the blood to the head (the carotid artery), in the artery of the arm (the humeral artery), in the artery of the lower extremity (the femoral artery); in a word, in the minute and remote capillary, and in the large trunk near the heart.

That the arterial tubes do possess and exert a truly vital power, modifying the current of the blood they contain, is indubitably established.

1. If in a living animal the trunk of an artery be laid bare, the mere exposure of it to the atmospheric air causes it to contract to such a degree that its size becomes obviously and strikingly diminished. This can result only from the exertion of a vital property, for no dead tube is capable in such a manner of diminishing its diameter.

2. If during life an artery be opened, and the animal be largely bled, the arteries become progressively smaller and smaller, as the quantity of blood in the body diminishes. If the bleeding be continued until the animal dies, and the arteries of the system be immediately examined, they are found to be reduced to a very small size; if again examined, some time after death, they are found to have become larger, and they go on growing successively larger and larger until they regain nearly their original magnitude, which they retain until they are decomposed by putrefaction.

3. M. Poiseuille distended with water the artery of an animal just killed. This water was urged by the pressure of a given column of mercury. The force of the reaction of the artery was now measured by the height of a column of mercury which the water expelled from the artery could support. It was found that the artery reacted with a force greater than that employed to distend it, and greater than the same artery could exert some time after death; but since mechanical reaction can never be greater than the force previously exerted upon it, it follows that the excess of the reaction indicated in this case was vital.

4. If an artery be exposed, and a mechanical or chemical stimulus be applied to it, its diameter is altered, sometimes becoming larger and sometimes smaller, according to the kind of agent employed.

The arterial trunks and branches are capable of enlarging and diminishing their diameter by virtue of a vital endowment. There is complete evidence that the exertion of this vital power on the part of the arterial trunk is not to communicate to the blood the smallest impulsive force: the engine constructed for the express purpose of working the current generates all the force that is required; but the labour of the engine is economized by imparting to the tubes that receive the stream a vital property, by which they remove the physical obstructions to its motion.

Driven by the heart through the arterial branches into the capillaries, the blood courses along these minute vessels urged by the same power. If an experimenter so dispose the circulation of the limb of an animal that the flow of blood be confined to the branches of a single artery, and a corresponding vein, it is found that the blood stagnates in the vein whenever the current in the artery is stopped by a ligature; but no sooner is the ligature removed from the artery than the blood begins again to flow freely along the vein, the capillaries of the artery which have to send on the current to those of the vein being now again within the influence of the heart. There is good reason to suppose that the blood, in its progress through the capillaries, is aided by the attraction which the tissues around exert upon it whilst it is fresh from the arteries. To such attractions the exhausted blood, which had passed far along the capillary, is indifferent, so that the fresh blood will urge before it that which is stale, and then, itself becoming effete, will be driven on by the advance of new blood from the artery. Such a power has been termed "capillary force."

It was found by Dr. Hales, that, under ordinary circumstances, the blood rises in a tube connected with a vein to the height only of six inches, while it has been shown that in the artery it ascends as high as ten feet. This prodigious difference between the venous and the arterial tension led to the conclusion that the impulsive force of the heart was all but exhausted before the blood reached the veins, and set physiologists on the search for other powers to carry on the venous circulation. It was overlooked that the blood has an open and ready escape from the great trunks of the veins through the right chambers of the heart, and that, in consequence of this free escape of their fluid, these vessels indicate no greater tension than is just sufficient to lift the blood to the heart, and to overcome friction.* M. Magendie, having laid bare the chief artery and vein of a living limb, and having raised the vessels in such a manner that he could place a ligature around the former, without including the latter, found that the flow of blood from a puncture made below a ligature on the vein, was rapid or slow, according as the heart was allowed to produce a greater or less degree of tension in the artery, which tension was regulated by compressing the artery between the fingers.

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* See this matter very ably discussed in Dr. Arnott's excellent work on the "Elements of Physics," vol. i.

After a similar preparation of a limb, a ligature was placed around the vein; a tube was then inserted into it; it was found that the blood ascended in the tube from the obstructed vein just as high as from the artery.

Thus we are able to trace the action of the heart from the beginning to the end of the circle. Of this circle it is the great moving power; but it is a living engine, acting in combination with living vessels. The force it exerts is a vital force, economized by the agency of a vital property communicated to the vessels, by virtue of which they remove physical obstruction to the progress of the stream through its channels.

In this account of the powers that move the blood, no notice has been taken of the physical agents supposed to act as auxiliaries to the heart, in carrying on the circulation, such as the suction power of the thorax, and of the auricles of the heart, and the capillary attraction of the vessels; because, without questioning the existence of such agents, or denying that advantage may be taken of them, it seems pretty clear that their influence is but trivial, and that they assumed importance only when the vital endowments of the tissues were not well understood.

The vital power, which it has been shown is possessed by the arterial trunks and branches, is still more intense in the minute capillaries. If alcohol, strong acetic acid, naphtha, and other stimulating fluids be injected into the arteries of a living animal, it is found that they are not transmitted through the capillaries at all, or, at all events, that they make their way through them with extreme difficulty; whereas mild, unirritating fluids pass with rapidity and ease. Wedemeyer exposed and divided the main artery in the fore-leg of a horse, together with the corresponding vein in the shoulder. Several syringes-full of tepid water were now injected into the lower end of the artery. The gentlest pressure was sufficient to force the fluid through the capillaries. At each injection the water issued in a full stream from the aperture of the vein, the flow of the fluid ceasing as soon as the injection was stopped. Next, instead of water, four syringes-full of pure cold brandy were injected. To propel this fluid through the capillaries, so as to render its smell and taste perceptible at the aperture of the vein, required a great degree of pressure; and when at last the fluid issued from the vein it merely trickled in a feeble stream.

The experiment being repeated on another horse, with vinegar, six syringes-full of which being injected in rapid succession, at first this fluid passed as easily as water, afterwards it flowed with greater difficulty, and in a small stream; before long the force required to propel it was extreme, and at last the obstruction to its passage became complete, so that no fluid whatever issued from the vein.

These experiments, whenever repeated, afforded the same result, and they demonstrate that the capillaries are capable of being stimulated to contract upon their contents, and that they can contract with such force as to stop the current. It is manifest that the power by which they do this is vital, because after death all fluids, the mildest and the most acrid, pass through them with equal facility.

Drs. Thompson, Philip, Hastings, and others in this country, have applied stimulants of various kinds to the capillary arteries, in order to observe with the microscope the changes which the vessels undergo. The results of these experiments, performed independently, agree with each other; and all the observers concur in stating that those results are so obvious and decisive as to admit of no question. Wedemeyer, fully aware of all that had been done on this subject by the English physiologists, repeated their experiments with his usual patience and care, vigilantly watching the effects with his microscope. His observations completely coincide with those of our countrymen. The circulation being observed in the mesentery of the frog, and in the web of its foot, it was apparent that no change whatever took place in the diameter of the small arteries, nor in that of the capillaries, as long as the circulation was allowed to go on in its natural state; but as soon as stimulants were applied to them an alteration of their diameter was visible. Alcohol, without much apparent contraction of the vessels, stopped the flow of the blood. Muriate of soda, in the course of three or four minutes, caused the vessels to contract one-fifth of their calibre, which contraction was followed by dilatation and gradual retardation and stoppage of the blood. Ammonia caused immediate and direct dilatation, and the effect of galvanism was still more striking. In a space of time varying from ten to thirty seconds, nay, sometimes immediately after the completion of the galvanic circle, the vessels contracted, some a fourth, others half, and others three-fourths of their calibre. The flow of the blood through the contracted vessels was accelerated. The contraction sometimes lasted a considerable time, occasionally several hours; in other instances the contraction ceased in ten minutes, and the vessels resumed their natural diameter. A second application of galvanism to the same capillaries seldom caused any material contraction.

The evidence, then, is abundant that stimulants are capable of modifying, to a great extent, the action of the capillary arteries, sometimes causing them to contract, at other times to dilate; sometimes quickening the flow of blood through them, at other times retarding it, and frequently altogether arresting its motion. This contractile power of the capillaries must be a vital endowment, for no such property is possessed by any substance destitute of life, and there is satisfactory evidence that it is communicated, regulated, and controlled by the organic nerves, which, as has been shown, increase as the size of the vessels and the thickness of their membranous tunics diminish. The powerful influence of these nerves upon the capillary vessels is placed beyond doubt or controversy by the obvious local changes produced in the capillary circulation by sudden, and even by mental impressions, by the flush of the cheek and the sparkle of the eye, at a thought conceived or a sound heard ; changes which can be effected, as far as we have any knowledge, by no medium excepting that of the nerves. The part performed by electricity, the physical agent by which it is conceived the nerves operate, will be considered hereafter.

Exerting upon each other a vital force of repulsion, under a vital influence derived from the organic nerves, urged by the vital contraction of the heart, the particles of the blood reach the extreme capillaries. The tissues are endowed with a vital attractive force, which they exert upon the blood—an elective as well as an attractive force: for in every part of the body, in the brain, the heart, the lung, the muscle, the membrane, the bone, each tissue attracts only those constituents of which it is itself composed. Thus the common current, rich in all the proximate constituents of the tissues, flows out to each. As the current approaches the tissue, the particles appropriate to the tissue feel its attractive force, obey it, quit the stream, mingle with the substance of the tissue, become identified with it, and are changed into its own true and proper nature. Meantime, the particles which are not appropriate to that particular tissue, not being attracted by it, do not quit the current, but passing on, are borne by other capillaries to other tissues, to which they are appropriate, and by which they are apprehended and assimilated. When it has given to the tissues the constituents with which it abounded, and received from them particles no longer useful, and which would become noxious, the blood flows into the veins to be returned by the pulmonic heart to the lung, where, parting with the useless and noxious matter it has accumulated, and, replenished with new proximate principles, it returns to the systemic heart, by which it is again sent back to the tissues.

But all that we can see, with the best aid we can get, does but bring us to the confines of the grand operations that go on, of which we are altogether ignorant. Arterial blood is conveyed by the arteries to the capillaries ; but before it has passed from under the influence of the capillaries it has ceased to be arterial blood. Arterial blood is conveyed by the carotid artery to the brain ; but the cerebral capillaries do not deposit blood, but brain. Arterial blood is conveyed by its nutrient arteries to bone, but the osseous capillaries do not deposit blood, but bone. Arterial blood is conveyed by the muscular arteries to muscle, but the muscular capillaries do not deposit blood, but muscle. The blood conveyed by the capillaries of brain, bone, and muscle is the same, all comes alike from the systemic heart, and is alike conveyed to all the tissues; yet in the one it becomes brain, in the other bone, and in the third muscle. Out of one and the same fluid these living chemists manufacture cuticle, and membrane, and muscle, and brain, and bone; the tears, the wax, the fat, the saliva, the gastric juice, the milk, the bile, all the fluids, and all the solids of the body.

The practical applications of these phenomena are numerous and most important; but they can be clearly and impressively stated only when the operation of the physical agents which influence the circulation, and which proportionally affect life and health, has been explained.

CHAPTER XII.

OF RESPIRATION.

Respiration in the plant; in the animal—Aquatic and aërial respiration—Apparatus in man—Trachea, Bronchi, Air Vesicles—Pulmonary artery—Lung—Respiratory motions: inspiration; expiration—How in the former air and blood flow to the lung; how in the latter air and blood flow from the lung—Relation between respiration and circulation—Quantity of air and blood employed in each respiratory action—Calculations founded on these estimates—Changes produced by animal respiration on the air: changes produced by vegetable respiration on the air—Changes produced by respiration on the blood—Respiratory function of the liver—Uses of respiration.

No organized being can live without food, and no food can nourish without air. In all creatures the necessity for air is more urgent than that for food; for some can live days, and even weeks, without a fresh supply of food, but none can enjoy active life without a constant renewal of the air.

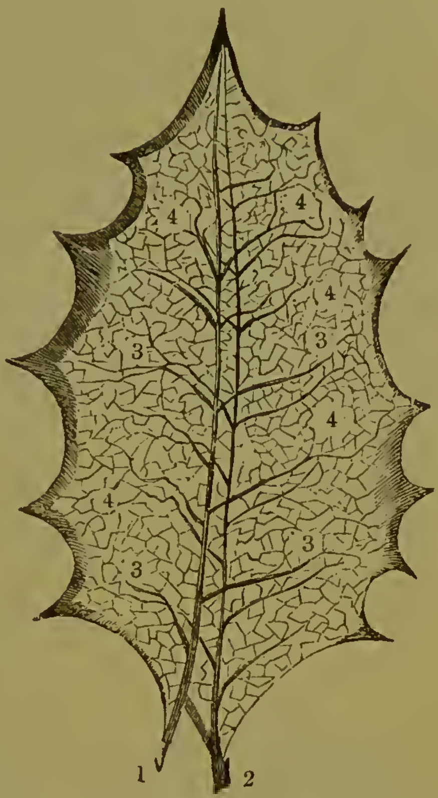
The food having undergone the requisite preparation in the apparatus provided for its assimilation, is brought into contact with the air, from which it abstracts certain principles, and to which it gives others in return. By this interchange of principles the composition of the food is changed: it acquires the qualities necessary for its combination with the living body. The process by which the air is brought into contact with the food, and by which the food receives from the air the qualities which fit it for becoming a constituent part of the living body, constitutes the function of respiration.

In the plant, the air and the food meet in contact and react on each other in the leaf. The crude food of the plant having in its ascent from the root through the stalk, received successive additions of organic substances, by which its nature is assimilated to the chemical condition of the proper nutritive fluid of the plant, undergoes in the leaf a double process; that of Digestion and that of Respiration. The upper surface of the leaf is a digestive apparatus, analogous to the stomach of the animal; the under surface of the leaf is a respiratory apparatus, analogous to the lung of the animal. For the performance of this double function, incessantly carried on by the leaf, its organisation is admirably adapted.

The solid skeleton of the leaf consists of a net-work composed partly of woody fibres and partly of spiral vessels which proceed from the stem, and which are called veins (Fig. 74, 1, 3). In the interstices between the veins is disposed a quantity of cellular tissue, termed the parenchyma of the leaf (Fig. 74, 4): the whole is enveloped in a membrane, called the cuticle (Fig. 75, 1), which is furnished with apertures denominated stomata, or stomates (Fig. 76).

The cuticle consists of a layer of minute cellules, colourless, transparent, without vessels, without organic particles of any kind, and probably filled with air (Fig. 75, 1). These cellules open externally, at certain portions of the cuticle, by apertures or passages which constitute the stomates, and which present the appearance of areolæ with a slit in the centre (Fig. 76). They form a kind of oval sphincters, which are capable of opening or shutting, according to circumstances, and they are disposed on both surfaces of the leaf, but most abundantly on the under surface, excepting in leaves which float on water, in which they are always on the upper surface only.

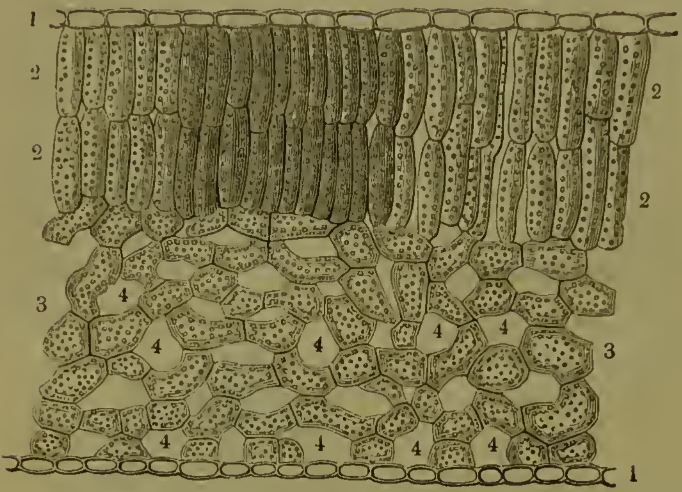
Fig. 74.



View of the net-work which forms the solid structure of the leaf, and which consists partly of woody fibres, and partly of spiral vessels. 1, vessels of the upper surface; 2, vessels of the under surface; 3, distribution of the vessels through the substance of the leaf; 4, interspaces between the vessels occupied by parenchyma or cellular tissue.

The cellular tissue or parenchyma, immediately beneath the cuticle, when examined in thin slices, and viewed under a microscope with a high magnifying power, presents a regular structure disposed in perfect order. It consists, on the upper surface, of a layer, and sometimes of two and even three layers, of vesicles of an oblong or cylindrical form, placed perpendicularly to the surface of the leaf, set close to each other (Fig. 75, 2), and filled with organic particles constituting the green matter which determines the colour of the leaf. On the under surface, on the contrary, the vesicles, which are larger than the cylindrical, are of an irregular figure, and are placed in an horizontal direction, at such distances as to leave wide intervals between each other (Fig. 75, 3); yet uniting and anastomosing together, and thus forming a reticulated tissue, presenting the appearance of a net with large meshes (Fig. 75, 3).

Fig. 75.

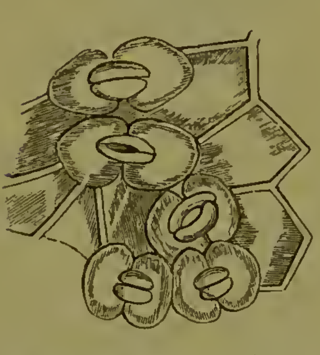


Vertical section of the leaf as it appears when seen highly magnified under the microscope. 1, cells of the cuticle filled with air; 2, double series of cylindrical cells occupying the upper surface of the leaf filled with organic particles; 3, irregular cells forming a reticulated texture occupying the under surface of the leaf; 4, interspaces between the cells, termed the intercellular passages or air chambers.

A leaf, then, consists of a double congeries of vesicles containing organic particles, penetrated by woody fibre and air vessels (which is probably the true nature of the spiral vessels), the whole being enclosed within a hollow stratum of air-cells.

The crude sap, composed principally of water, holding in solution carbonic acid, acetic acid, sugar, and a matter analogous to gum, is transmitted through the leaf-stalk to the cylindrical vesicles of the upper surface of the leaf. These vesicles exhale a large proportion of the water; the evaporation of which is powerfully assisted by the action of the sun's rays. The primary effect of the evaporation carried on in the cylindrical vesicles, is the condensation of the organic matters contained in the sap.

Fig. 76.



View of the stomata of a leaf, some of them represented as open and others as closed.

At the same time that the cylindrical vesicles pour the superfluous water of the sap into the surrounding atmosphere, they abstract from the atmosphere in return carbonic acid, which, together with that already contained in the sap, is decomposed. The oxygen is evolved; the carbon is retained. The physical agent by which this chemical change, which constitutes the digestive process of the plant, is effected, is the solar ray; hence the vesicles which contain the fluid to be decomposed, are placed on the upper surface of the leaf, where their contents are fully exposed to the action of the sun; and hence also this process takes place only during the day, and most powerfully under the direct solar ray: but although the direct influence of the sun be highly conducive to the process, yet it is not indispensable to it; for it goes on in daylight although there be no sunshine.

After the sap has been elaborated in the cylindrical vesicles, by the exhalation of its watery particles, by the condensation of its organic matter, by the retention of carbon and the evolution of oxygen, it is transmitted to the reticulated vesicles of the under surface of the leaf. These vesicles, large, loose, and expanded, as they have an opposite function to perform, are arranged in a mode the very reverse of the cylindrical: in such a manner as to present the greatest possible extent of surface to the surrounding air: at the same time the broad interspaces between them are so many cavernous air-chambers into which the air is admitted through the stomates. The cylindrical vesicles, exposed to the direct rays of the sun, are protected by the closeness with which they are packed; and by the small extent of surface they present to the heavens: the reticulated vesicles, whose function requires that they should have the freest possible exposure to the surrounding air, are protected from the solar ray, first by their position on the under surface of the leaf; and, secondly, by the dense and thick barrier formed by the stratum of cylindrical vesicles.

In the cylindrical vesicles carbonic acid is decomposed; in the reticulated vesicles, on the contrary, carbonic acid is re-formed. The oxygen required for this generation of carbonic acid is abstracted partly from the surrounding air; the carbon is derived partly, perhaps, from the air, but chiefly from the digested sap, and the carbonic acid, formed by the union of these elements, is evolved into the surrounding atmosphere.

This operation, which is strictly analogous to that of respiration in the animal, in which carbonic acid is always generated and expired, is carried on chiefly in the night. In this manner, under the influence of the solar light, the leaf decomposes carbonic acid; retains the carbon and returns the greater part of the oxygen to the air in a gaseous form. At night, in the absence of the solar ray, the leaf absorbs oxygen, combines this oxygen with the materials of the sap to produce carbonic acid, which, as soon as formed, is evolved into the surrounding air. But the quantity of oxygen given off in the day is greater than the amount converted into carbonic acid by night; so that the operation of vegetables on the air tends to purify it of carbonic acid.

The result of these chemical actions is the conversion of the crude sap into the proper nutritive juice of the plant. When it reaches the cylindrical vesicles, the sap is colourless, not coagulable, without globules, composed chiefly of water holding in solution carbonic and acetic acids, sugar, gum, and several salts; when it leaves the reticulated vesicles it is a greenish fluid, partly coagulable and abounding with organic particles under the form of globules. Its chemical composition is now wholly changed; it consists of resinous matter, starch, gluten, and vegetable albumen. It is now thoroughly elaborated nutritive fluid; the proper food of the plant (cambium); rich in all the principles which are fitted to form vegetable secretions: it is to the plant what arterial blood is to the animal, and, like the vital fluid formed in the lung, the cambium elaborated in the leaf, is transmitted to the different parts and organs of the plant to serve for their nutrition and development.

The formation of this nutritive fluid by the plant is a vital process, as necessary to the continuance of its existence, as the process of sanguification is necessary to the maintenance of the life of the animal. If the plant be deprived of its leaves, if the cold destroy, or the insect devour them, the nutrition of the plant is arrested; the development of the flowers, the maturation of the fruit, the fecundation of the seeds, all are stopped at once, and the plant itself perishes.

The proper nutritive juice of the plant, completed by the process of respiration, is formed by the elaboration of organic combinations of a higher nature than those afforded by the sap. Acid, sugar, gum, are converted into the higher organic compounds, resin, gluten, starch, albumen, probably by chemical processes, the result of which is the inversion of the relative proportions of oxygen and carbon. In the organic matters contained in the sap, the proportion of oxygen, compared with that of carbon, is in excess; on the contrary, in the higher compounds contained in the cambium, the carbon preponderates: by the inversion of the relative proportions of these two elements, the organic compounds of a lower nature, appear to be changed into those of a higher; to be brought into a chemical condition nearer to that of the proper substance of the plant; a condition in which they receive the last degree of elaboration preparatory to their conversion into that substance.

In the process of respiration in the animal, as in the plant, parts of the digested aliment mix with the air; parts of the air mix with the digested aliment; and by this interchange of principles, the chemical composition of the aliment acquires the closest affinity to that of the animal body; is rendered fit to combine with it; fit to become a constituent part of it.

The extent and complexity of the respiratory apparatus in the animal, is in the direct ratio of the elevation of its structure and the activity of its function, to which the quantity of air consumed by it is always strictly proportionate.

The process of respiration in the animal is effected by two media, air and water; but the only real agent is the air; for the water contributes to the function only by the air contained in it. Respiration by water is termed aquatic, that by the atmosphere, atmospheric or aërial respiration.

The quantity of air contained in water being small, aquatic is proportionally less energetic than aërial respiration; and, accordingly, the creatures placed at the bottom of the animal scale, having the simplest structure and the narrowest range of function, are all aquatic.

Whatever the medium breathed, respiration in the animal is energetic in proportion to the extent of the respiratory surface exposed to the surrounding element. As the water-breathing animals successively rise in organisation, their respiratory surface becomes more and more extended, and a proportionally large quantity of water is made to flow over it. It is the same in aërial respiration: the higher the animal, the greater the extent of its respiratory surface; and the larger the bulk of air that acts upon it.

Whatever the medium breathed, respiration is effected by the contact of fresh strata of the surrounding element with the respiratory surface. The mode in which this constant renewal of the strata is effected, is either by the motion of the body to and fro in the element; or by the creation of currents in it, which flow to the respiratory surface. A main part of the apparatus of respiration consists of the expedients necessary to accomplish these two objects; and that apparatus is simple, or complex, chiefly according to the extent of the mechanism requisite to effect them.

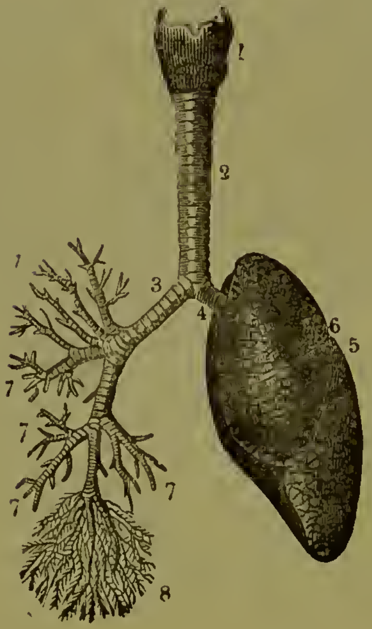
Whatever the medium breathed, the organic tissue which constitutes the essential part of the immediate organ of respiration is the skin. In all animals the skin covers both the external and the internal surfaces of the body. When forming the external envelope, this organ commonly retains the name of skin; when forming the internal lining, it is generally called mucous membrane; and in all animals, either in the form of an external envelope, or an internal lining, or by both in conjunction, or by some localisation and modification of both, the skin constitutes the immediate organ of respiration. In different classes of animals it is variously arranged, assumes various forms, and is placed in various situations, according to the medium breathed, and the facility of bringing its entire surface into contact with the surrounding element.

In man there are two respiratory organs, called lungs (Fig. 47), of nearly equal size, which, together with the heart, completely fill the large cavity of the thorax, their external surface being in immediate contact with the thoracic walls. One of these is placed on the right side of the body, constituting the right lung, and the other on the left, constituting the left lung. Each lung is divided by deep fissures, into large portions called lobes (Fig. 47), of which there are three belonging to the right, and two to the left lung. Each lobe is subdivided into innumerable smaller parts termed lobules, while the lobules successively diminish in size until they terminate in minute vesicles that constitute the great bulk of the organ.

The complete centralization of the respiratory function which takes place, renders the apparatus exceedingly complex both on account of the expedients which are necessary to obtain the requisite extent of surface, in the small allotted space, and to bring into contact within that space the fluids that are to act on each other.

The apparatus consists of a vessel to carry the air to the blood; a vessel to carry the blood to the air; an organ in which the air and the blood meet; and an organization by which both fluids are put in motion. The vessel that carries the air to the blood is the windpipe (Fig. 77, 1, 2); the vessel that carries the blood to the air is the pulmonary artery (Fig. 71); the organ in which the blood and the air meet is the lung; the organisation which puts the air in motion is the structure of bones, cartilage, and muscles, called the thorax (Fig. 41), and the engine that communicates motion to the blood is the right ventricle of the heart (Fig. 70).

Fig. 77.



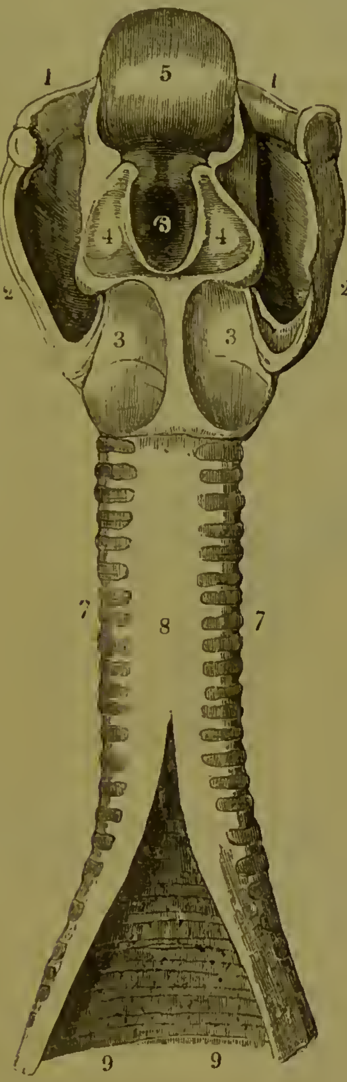
View of the air tubes and lung. 1, the larynx; 2, trachea; 3, right bronchus; 4, left bronchus; 5, left lung; the fissures denoted by the two lines which meet at 6, dividing it into three lobes, and the smaller lines on its surface marking the division of the lobes into lobules; 7, large bronchial tubes; 8, minute bronchial tubes terminating in the air cells or vesicles.

The windpipe is a tube which extends from the mouth and nostrils to the lung (Fig. 77, 2). It is attached to the back part of the tongue, and passes down the neck immediately before the œsophagus, or the tube which leads to the stomach.

In the different parts of its course the windpipe is differently constructed, performs different offices, and receives different names according to the diversity of its structure and function. The first division of it is called the larynx (Fig 77, 1), the second the trachea (Fig. 77, 2), and the third the bronchi (Fig. 77, 3, 4, 7).

The first portion of the windpipe, called the larynx (Fig. 77), constitutes the organ of the voice. It is situated at the upper and fore part of the neck, immediately under the bone to which the root of the tongue, called the os hyoides (Fig. 78, 1), is attached. The larynx forms a very complex structure, and is composed of a variety of cartilages, muscles, ligaments, membranes, and mucous glands (Fig. 78, 2, 3, 4, 5). At its upper part is a narrow opening of a triangular figure called the glottis (Fig. 78, 6), by which air is admitted to and from the lung. Immediately above this opening is placed the cartilage, which obtains its name from its situation, *epiglottis* (Fig. 78, 5), which is attached to the root of the tongue, and which may be distinctly seen in the living body by pressing down the tongue.

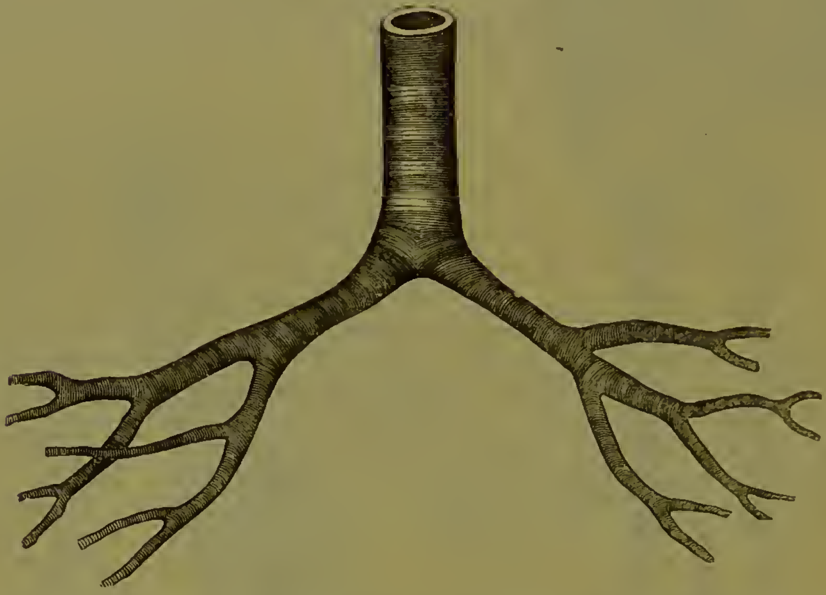
Fig. 78.



Posterior view of the larynx and trachea. 1, the os hyoides; 2, thyroid cartilage; 3, cricoid cartilage; 4, arytenoid cartilages, separated from each other; 5, epiglottis; 6, opening of the glottis; 7, termination of the cartilaginous rings of the trachea; 8, the ligamentous portion of the trachea; 9, trachea laid open, showing its internal mucous surface and follicles, with the anterior portion of the cartilaginous rings appearing through it.

The epiglottis is highly elastic, and is an agent of no inconsiderable importance in deglutition and speaking. During the action of deglutition the epiglottis is carried completely over the glottis, partly because it is necessarily forced backwards, when the tongue passes backwards in delivering the food to the pharynx, partly because it is carried backwards by certain minute muscles which act directly upon it, and partly through the movement of the larynx, which is brought upwards and forwards beneath it. The moment the action of deglutition has been performed the epiglottis springs from the aperture of the glottis, by the return of the tongue, &c., to their former position. During the act of speaking the column of air which is expelled from the lung, which rushes through the glottis, and which thus forms the voice, strikes against the epiglottis, and the voice becomes thereby in some degree modified.

Fig. 79.



View of the trachea, showing, first, the division of the tube into the right and left bronchus, and the subdivision of the bronchi into the bronchial tubes; and, secondly, the membranous and cartilaginous tissues of which the organ is composed.

The trachea (Fig. 77, 2) is a tube with firm and substantial walls. It is kept always open to admit of the constant passage of air to and from the lungs. For this purpose its walls have horizontal bars of cartilage imbedded within them at short intervals.

These embrace a sufficient portion of its circumference, but do not quite surround it, because they would then prevent any variation of its calibre, such as is sometimes necessary, for instance, in coughing, where the narrowing of the tube increases the force of the rush of air upwards. The rings are in the front and sides of the trachea; but the back part (Fig. 78, 7) is membranous in its structure, and is composed of muscle and elastic tissue in addition to the common supporting fibrous membrane which is present throughout the whole tube-wall. The muscle runs for the most part horizontally, connecting the ends of the incomplete rings; its action is to lessen the calibre of the tube. The elastic fibres, on the contrary, are chiefly disposed along the length of the tube according to the requirements of their office, which is to shorten the extended trachea when the lungs with their roots ascend in expiration. The trachea runs down in the middle line of the neck close in front of the œsophagus or gullet, and passes into the chest, descending as low as the level of the third dorsal vertebra. Arrived thereabouts, it parts into two trunks (Fig. 79), quite like it in structure, each of which passes outwards in the root of the lung on its own side. Each enters the lung in company with the great blood-vessels by which that organ is copiously supplied (see Fig. 48), and soon commences a process of subdivision into successively smaller and smaller portions, which radiate away from the roots towards the circumference of the lung, some reaching up nearly to its surface, others losing themselves in the substance between the branching tubes.

These smaller tubes within the lung have essentially the same structure as the trachea, except that the cartilage is no longer disposed in even rings, but is found in irregular-shaped pieces, and gradually disappears in the smaller tubes, except as a little patch at the spots of division to keep the mouths of the tubes patent; even these at length cease, and are lost in the minutest tubes, where they pass into the air-cells.

The whole of these air passages are lined throughout with a mucous membrane, the surface of which is covered with ciliated epithelium (Fig. 20), the moving filaments of which are so set to their work that they act in concert to waft the mucus, and any particles of dust that happen to have gained entrance, always upwards to the throat: if these are small enough, the upward current which the cilia on the surface produce, gently but steadily moves them back, floating on the superfluity of that mucus which the lining membrane is constantly yielding; if larger, or more irritating or hurtful, then the breathing powers unite in a concerted effort to drive out the enemy of their comfort and peace. This effort is called coughing, and it is executed by a very nicely-timed combination of distinct and widely separate organs disposed within the brain and in the face, in the chest, and in the abdomen. First the chest is filled with air; then the gates of the glottis (Fig. 78, 6) are closed whilst the muscles of expiration exert themselves to force the air out of the chest; in the mean time the encircling muscular fibres of the bronchial tubes contract and narrow their calibre. The air is compressed by the efforts of the expiratory muscles until the glottis suddenly opens and lets it out, its velocity being the greater for the narrowing of the tubes: just at this instant the soft palate (Fig. 81), which usually droops in the throat, is lifted, and closes the way to the nose, so that the air rushes out of the mouth, and if the cough is successful, bears along with it the annoying matter. Of course, if the annoyance arises from the presence of an excess of mucus poured out by the lining membrane of the tubes, or by blood or other substances from within the lung, the intent and method of the proceedings are the same as in the case of unwelcome particles from without.

The trachea then divides to form the bronchial tubes, much as the trunk of a tree spreads into branches (Fig. 77, 3, 7, 8); and as the root of a tree buries itself in smaller and smaller rootlets throughout the soil in which it grows, so the bronchial tubes by successive subdivisions spread in the lung and carry air everywhere throughout its substance. This is parcelled out into small portions called lobules, separated from each other by a little areolar tissue, and each of these receives one of the smallest divisions of the bronchial tubes, which upon entering the lobule loses all its proper structure; the muscle, elastic tissue, and ciliated membrane disappear, and the continuation of the little tubes widening slightly opens freely on all sides into passages like itself, and they again open freely into bubble-like cells, the shape of which is made polyhedral by their mutual coaptation and pressure. The walls of the passage and cells are extremely thin, and upon them is spread out a close web of minute vessels, the surface of which is exposed to the air, always filling the cells of the lung. Though each cell is so small as to be only just visible to the naked eye, yet their number is so vast that their united surface would, it is calculated, extend over the body thirty times. It is in these cells that the blood is purified from the volatile refuse which it has collected in its course through the body. The bronchial tubes are mere air channels, wonderfully fitted with means of defending themselves from the presence of hurtful substances, first by an ever-watchful guard at the entrance, which has power instantaneously to close the strong gates of the glottis, and then by an admirably contrived apparatus for sending back such minor intruders as are not significant enough to provoke the glottis to close.

The blood, after circulating through the body, arrives exhausted and impure at the auricle of the right or pulmonary side of the heart (Fig. 70), and passes from this receptive cavity into the right ventricle (Fig. 70), from whence it is driven through the pulmonary artery into either lung: the great trunk of this artery parts into two large branches, one of which runs close to the bronchial tube into each lung, where the blood-vessel follows the air-vessel (Fig. 48), dividing along with it, and reaching with it in smaller and smaller branches away to the air cells; all round these the blood-vessels spread in a close web of delicate capillaries, the walls of which are so thin that the vital air freely permeates them, and gains access to the blood, whilst the volatile impurities of the blood escape to the air of the cells in exchange: through this capillary web the blood reaches the fine commencing roots of the pulmonary vein, which rises from the web just as the arteries sink into it, and by uniting and reuniting gather themselves up into two great trunks, which come out of each lung (Fig. 48, pul. vein) close to where the artery enters, and at once go into the left auricle in readiness to be again diffused through the body. In this way the air meets the blood. The object of the remaining portion of the respiratory apparatus is to produce those movements which must drive out the exhausted air and bring a fresh supply. This is accomplished by the mechanism and action of the thorax and diaphragm (Fig. 41).

These organs, which act in concert, are so constructed and disposed, that when in action they give to the chest two alternate motions, one that by which its capacity is enlarged; and the other that by which it is diminished. These alternate movements are called the motions of respiration. The motion by which the capacity of the chest is enlarged is termed the action of inspiration, and that by which it is diminished the action of expiration.

The action of inspiration, or that by which the capacity of the chest is enlarged, is effected by the combined movements of the thorax and diaphragm; by the expansion of the thorax and by the descent of the diaphragm.

The osseous portion of the thorax has been fully described. The chief boundaries of the cavity of the thorax before, behind, and at the sides, are osseous; below the boundary is muscular, being formed by the diaphragm (Fig 41).

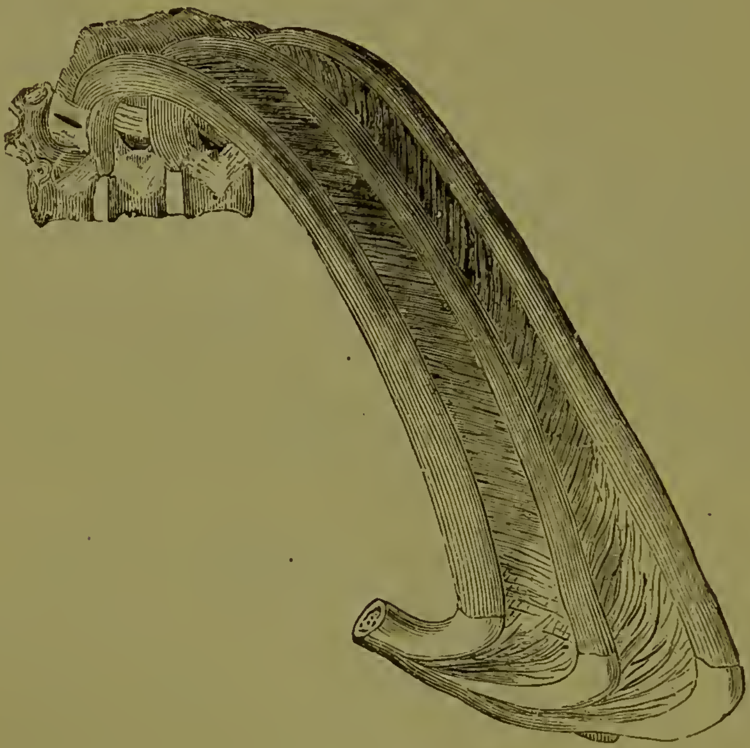
Externally the thorax is convex, and enveloped by muscle and skin; internally it is concave, and lined by a continuation of the same membrane which envelops the lungs, the pleura. But that portion of the pleura which lines the internal wall of the thorax is called the costal pleura (pleura costalis), in contradistinction to that which envelops the lungs, which is termed the pulmonary pleura, or pleura pulmonalis. By the costal pleura, a thin but firm and strong membrane, smooth, polished, and like all the membranes of its class, kept in a state of perpetual moisture and suppleness, by a fluid secreted at its surface, the movements of the thorax are facilitated, at the same time that they are prevented from injuring the delicate organs contained it it.

The moveable parts of the osseous portion of the thorax are the ribs and sternum.

The ribs form a series of moveable arches, the convexity of the arches being outwards, and the whole being generally disposed in an oblique direction (Fig. 41), though the first rib springs from the vertebral column at nearly a right angle. The others slope downward successively more and more, and their forward ends are turned up, whilst the cartilages which continue them onward ascend toward the breast-bone, to which the upper seven are attached (Fig. 41).

In consequence of this conformation and arrangement of the ribs, every degree of motion which is communicated to them necessarily influences the capacity of the space they enclose. In ascending they carry forward the breast-bone, and so increase the measure of the chest from before backward, whilst from the combination of outward with downward curvature in their arrangement, the muscular force pulling along the upper edges causes them to twist outward as they ascend, an effect which is rendered possible through the yielding of the cartilage which connects them to the sternum: by the outward movement of the convexity of each rib the chest is widened from side to side, and as the length of the curve increases, and the degree of curvature augments from above downwards (Fig. 41), this widening is greatest at the lower part of the chest. Thus the respiratory movement of the thorax results in an expansion of the chest in all directions, increasing evenly towards its lowermost part.

Fig. 80.



View of the intercostal muscles which fill up the interspaces between the ribs. These muscles consist of a double layer of fibres, the external and the internal, which cross or intersect each other.

The muscles by which these motions of the ribs are effected in ordinary inspiration connect the adjacent bodies of the ribs, and are called intercostal (Figs. 41 and 80); they extend obliquely from rib to rib in two layers, the outer of which run downwards and forwards, whilst the inner run downwards and backwards: in their action they pull towards that end which is nearer to the spine; and thus the external intercostals, whose upper end is nearer the spine, pull the lower rib upwards, and so act in inspiration; whilst the internal intercostals, whose lower end is nearer the spine, pull the upper rib downwards, and so act in expiration.

Besides the muscles that move the ribs, and enlarge the circumference of the chest, a great agent in respiration is formed by the moveable floor of the thorax, which is called diaphragm or midriff (Fig. 41, *g*, *c*, *h*). This is a great expanded muscle, so disposed as to form an arched roof to the abdomen, the convexity of which extends up into the chest. It is firmly attached to the spine by long descending fleshy columns (Fig. 41, *h*), and also all round the lower border of the bony thorax to the ends of the ribs by fleshy fibres. Its middle part is a sheet of strong membrane, and with its edges the muscle from the spine and ribs is continuous, so that altogether the arch is fleshy at the circumference and tendinous in the middle: when the muscular borders relax and lengthen, they allow the middle tendon to rise as high into the thorax as the fifth rib (see Fig. 41), and by this means they decrease the vertical capacity of the cavity of the chest; but when the muscular borders contract and shorten, they draw down the central tendon towards the edge of the ribs, and thus enlarge greatly the capacity of the chest.

The pericardium or bag which contains the heart is firmly fixed to the upper surface of the diaphragm (Fig 47), and so is drawn down with it: thus the heart, which lies between the lungs and below their root, is made to accommodate by its descent the expanding lungs: when the diaphragm descends it presses on the contents of the abdomen. These make room for themselves by distending the soft walls, the muscles of which, when the diaphragm has finished acting, and has relaxed, come into play in their turn, and forcing back the viscera return them upon it, and so push it up into the thorax, whence to descend again at the next inspiration. The abdominal muscles then counteract the diaphragm, and they operate in forcing the air out of the chest not only so, but also by pulling down the ribs, to which they are directly attached: in thus emptying the thorax they are aided by the elasticity of the lungs and bronchial tubes, and also by that of the cartilages of the ribs, which are twisted in the inspiratory effort and recoil at its cessation.

Such is the mechanism by which the capacity of the thorax is alternately enlarged and diminished in the two alternate states of inspiration and expiration, and the mechanism thus adjusted works in the following mode.

Expiration succeeding to the state of inspiration, the ribs descend, the diaphragm ascends, the capacity of the thorax lessens, and the compressed lungs are forced within the smallest possible space. Then, inspiration, succeeding to the state of expiration, the ribs ascend and the diaphragm descends; the capacity of the thorax is enlarged, and the lungs freed from their pressure expand and fill the greater space obtained. In about a second and a half after the state of inspiration has been induced, that of expiration recommences; the motion of inspiration occupying about double the time of the motion of expiration, and these alternate conditions succeed each other in a regular and uniform course, day and night, during our sleeping and our waking hours to the end of life.

As long as the function is performed in a perfectly natural manner, a given number of these alternate movements takes place in a certain time, constituting what is termed the rhythm of the respiratory motions. These motions perfectly regular in number and time, are likewise, in the natural state of the function, performed only with a certain degree of energy; but they are variously modified at the command of the will; in obedience to numerous sensations and emotions; in the performance of a great variety of complex actions, and in different states of disease. These modifying circumstances may cause the action of inspiration to be more full and deep, and that of expiration to be more forcible and complete than natural; or they may cause both movements to be shorter and quicker than common: hence the distinction of respiration into ordinary and extraordinary.

In ordinary respiration, that is, when the respiratory motions are perfectly calm and easy, the ascent and descent of the ribs are scarcely perceptible; the action is confined almost exclusively to the ascent and descent of the diaphragm. In this condition the action of the intercostal muscles is to fix the ribs, and thus to afford fixed points which are essential to the action of the diaphragm. But in extraordinary respiration, that is, when circumstances happen in the economy which require that those motions should be extended, auxiliary sources can be put in requisition. There are many powerful muscles situated about the breast, shoulder and back (Figs. 54 and 55), which are capable of elevating the ribs and protruding the sternum to a very considerable extent. Where, for example, the fullest inspiration which it is possible to take is required, the bones of the shoulder and shoulder-joint are firmly fixed by resting the hands upon the knees, and then every muscle which has the slightest connexion with the thorax, either before or behind, capable of raising the ribs, is added to the inspiratory apparatus; at the same time that the abdominal muscles are relaxed to the utmost degree, in order to facilitate the ascent of the ribs and the descent of the diaphragm. If, on the contrary, the fullest possible expiration is required, the abdominal muscles contract most forcibly, and every other muscle which is capable of still farther depressing the ribs and of elevating the diaphragm is called into intense action. By these forcible and extraordinary efforts the thorax may be enlarged or diminished double its ordinary capacity.

Such are the mechanism and action of the powers which communicate to the thorax the motions by which its capacity is alternately enlarged and diminished, and by which the requisite impulse is communicated to the fluids which flow to and from the lungs in the different states of respiration; that is, by which air and blood flow to the lungs in the action of inspiration, and from the lungs in the action of expiration.

The mode in which air is transmitted to the lungs by the dilatation of the thorax, in the action of inspiration, is the following. The lungs are in direct contact with the inner surface of the thorax, and follow passively all its movements. When the volume of the lungs is reduced to its minimum by the diminished capacity of the thorax, in the state of expiration, they still contain a certain bulk of air. As their volume increases with the enlarging capacity of the thorax in the state of inspiration, this bulk of air having to occupy a greater space expands. By this expansion of the air in the interior of the lungs, it becomes rarer than the external air. Between the rarefied air within the lungs, and the dense external air, there is a direct communication by the nostrils, mouth, trachea, larynx, and bronchi. In consequence of its greater density, the external air rushes through these openings and tubes to the lungs and fills the air vesicles, the current continuing to flow until an equilibrium is established between the density of the air within the lungs and the density of the external air; and thus there is established the flow of a current of fresh air to the air vesicles.

The external air which, in obedience to the physical law that regulates its motion, thus rushes to the lung in order to fill the partial vacuum created by the dilatation of the thorax in inspiration, produces, in passing to the air vesicles, a peculiar sound. When the lungs are perfectly healthy, and the respiration is performed in a natural manner, if the ear be applied to any part of the chest, a slight noise can be distinguished both in the action of inspiration and that of expiration; a soft murmur, somewhat resembling the sound produced by the deep inspirations occasionally made by a person profoundly sleeping. This sound, though appreciable even by the naked ear, and though produced many times every minute, in every healthy human being from the first moment of the existence of the first man, had never been much attended to, until about the year 1816, when the stethoscope was discovered by accident. A physician, Dr. Laennec, of Paris, having occasion to examine a young female labouring under, as he supposed, some disease of the heart, and scrupling to follow his first impulse to apply his ear to the chest, chanced to recollect that solid bodies have the power of conducting sounds better than the air. Thereupon he procured a quire of paper, rolled it up tightly, tied it, and then applied one extremity to the patient's chest and the other to his ear. Profiting by the result, which was, that he could hear the beating of the heart much more distinctly than he could possibly feel it by the hand, he substituted for this first rude instrument a wooden cylinder, which he called a stethoscope or chest inspector. The attentive and practised use of this instrument is found to be capable of revealing to the ear all that is passing in the chest almost as clearly and certainly as it would be visible to the eye, were the walls of the chest and the tissues of its organs transparent. Besides the entrance of the air into the lung in inspiration, and its exit in expiration, even the motion of the blood in the heart, and in the great blood-vessels, are rendered by this instrument distinctly manifest to sense; and as the ear which has once become familiar with the natural sounds produced by these operations in the state of health, can detect the slightest deviation occasioned by disease, the practical application of this discovery has effected for the pathology of the chest, what the discovery of the circulation of the blood has accomplished for the physiology of the body.

We are thus able to form a clear conception of the mechanism and action of both parts of the complicated function of respiration. Almost all the points connected with the systemic circulation were established upwards of three hundred years ago, but many points connected with the pulmonic circulation have been established only recently. Our knowledge of the phenomena of both, and of their mutual relation and dependence, has been slowly increasing, and is at length tolerably complete; and now that we understand the exact office and working of each, we see that the action of the one is not only in harmony with that of the other, but co-operates with it, and renders it perfect.

From experiments performed by Dr. Dill and myself to ascertain the relation of respiration to circulation, it follows—

1. That the state of inspiration is favourable to the passage of the blood through the lungs. In the dilatation of inspiration they transmitted nearly double the quantity that passed in the collapse of expiration; or, as four ounces and five drachms are to two ounces and seven drachms.

2. That no degree of collapse to which the lungs can be reduced is capable of wholly stopping the flow of the blood through them. In the collapse of suspension and submersion they transmitted as much blood, with the exception of two drachms, as when death was produced by a blow on the head. In the greatest degree of collapse capable of

being produced by an exhausting syringe, they transmitted half as much as in the collapse of suspension and submersion.

3. That it is only a moderate degree of dilatation that is favourable to the transmission of the blood through the lungs. When the lungs are over-distended with air, they are capable of transmitting only an exceedingly small quantity of blood; when they are fully distended with water, they are incapable of transmitting a single drop of blood. In fact they can contain only a certain quantity of air and blood; and when either of these fluids preponderates, it can only be by the proportionate exclusion of the other. It will appear hereafter that these results are capable of applications of the highest interest and importance in the explanation of numerous phenomena of health and of disease.

Physiologists have laboured with great diligence to determine the exact quantity of air and blood which enters and which flows from the lung at each of the actions of respiration, and they have succeeded in obtaining tolerably precise results.

The quantity of air capable of being received into the lungs of an adult man, in sound health, at an inspiration, is determined with correctness by an instrument constructed by Mr. Green, analogous to one suggested by Mr. Abernethy. It consists of a tin trough, about a foot square, and six inches deep, three parts of which are filled with water. Into this trough is placed a three-gallon glass jar, open at the bottom, and graduated at the side into pints, half-pints, &c. To the upper end of the jar a flexible tube is affixed, having at its connexion a stop-cock. The lungs being emptied, as in the ordinary action of expiration, and the mouth applied to the end of the flexible tube, the nostrils being closed by the pressure of the fingers, the air is drawn out of the jar into the lungs by the ordinary action of inspiration. When as much air is thus drawn into the lungs as the air vesicles will hold, the stop-cock is closed, and the quantity of air inspired is ascertained by the rise of the water, the level of the water corresponding with the indications marked on the side of the jar.

The quantity of air which a person by a voluntary effort can inspire at one time is found, as might have been anticipated, to be different in different individuals. These varieties depend, among other causes, on the greater or less development of the trunk, on the presence or absence of disease in the chest, on the degree in which the lung is emptied of air by expiration previously to inspiration, and on the energy of the inspiratory effort. The greatest volume of air hitherto found to have been received by the lung, on the most powerful inspiration, is nine pints and a quarter. The average quantity which the lungs are capable of receiving in persons in good health, and free from the accumulation of fat about the chest, appears to be from five to seven pints. The latter is about the average quantity capable of being inspired by public singers.

But these measurements relate to the greatest volume of air which the lungs are capable of receiving, on the most forcible inspiration which it is possible to make, after they have been emptied by forcible expiration, and consequently express the quantity received in extraordinary, not in ordinary inspiration. The quantity received at an inspiration easy, natural, and free from any great effort, may be two pints and a half; but the quantity received at an ordinary inspiration, made without any effort at all, is, according to former observations which referred to the old Winchester measure, about one pint.

The quantity of air expelled from the lung by an ordinary expiration is probably a very little less than that received by an ordinary inspiration.

No one is able by a voluntary effort to expel the whole contents of the lungs. Observation and experiment lead to the conclusion that the lungs, when moderately distended, contain at a medium about twelve pints of air. As one pint is inhaled at an ordinary inspiration, and somewhat less than the same volume is expelled at an ordinary expiration, there remain present in the lungs, at a minimum, eleven pints of air. There is one act of respiration to four pulsations of the heart; and, as in the ordinary state of health there are seventy-two pulsations, so there are eighteen respirations in a minute, or 25,920 in the twenty-four hours.

About two ounces of blood are received by the heart at each dilatation of the auricles; about the same quantity is expelled from it at each contraction of its ventricles; consequently, as the heart dilates and contracts seventy-two times in a minute, it sends thus often to the lungs, there to be acted upon by the air, two ounces of blood. It is estimated by Haller that 10,527 grains of blood occupy the same space as 10,000 grains of water, so that if one cubic inch of water weigh 253 grains, the same bulk of blood will weigh 266⅓ grains.

It is ordinarily estimated that on an average one circuit of the blood is performed in 150 seconds; but it is shown that the quantity of air always present in the lungs contains precisely a sufficient quantity of oxygen to oxygenate the blood, while flowing at the ordinary rate of 72 contractions of the heart per minute, for the exact space of 160 seconds. It is therefore highly probable that this interval of time, 160 seconds, is the exact period in which the blood performs one circuit, and not 150 seconds, as former observations had assigned. If this be so, then 540 circuits are performed in the twenty-four hours; that is, there are three complete circulations of the blood through the body in every eight minutes of time.

But it has been shown that the weight of the blood is to that of water as 1.0527 is to unity, and that consequently 10,527 grains of blood are in volume the same as 10,000 grains of water.

From this it results that if in the human adult two ounces of blood are propelled into the lungs at each contraction of the heart, that is, 72 times in a minute, there are in the whole body precisely 384 ounces, or 24 pounds avoirdupois, which measure 692.0657 cubic inches, or within one cubic inch of 20 imperial pints, which measure 693.1847 cubic inches.

By an elaborate series of calculations from these data, Mr. Finlaison deduced general results, from which it follows that, in round numbers, there flow to the human lungs every minute nearly 18 pints of air (besides the 12 pints constantly in the air vesicles) and nearly 8 pints of blood; but in the space of twenty-four hours, upwards of 57 hogsheads of air and 24 hogsheads of blood.

Provision cannot have been made for bringing into contact such immense quantities of air and blood, unless important changes are to be produced in both fluids; and accordingly it is found that the air is essentially changed by its contact with the blood, and the blood by its contact with the air.

Chemistry has demonstrated the changes effected in the air. Common atmospheric air is a compound body, consisting of pure air and of certain substances diffused in it. Pure air is composed mainly of two gases, azote and oxygen, always present in fixed proportions. The substances diffused in pure air, and which are in variable quantity, are aqueous vapour and carbonic acid gas. These latter substances form no part of the chemical agents essentially concerned in the process of respiration. The only constituents of the air which are essentially concerned in the process of respiration are the two gases, azote and oxygen, the union of which, in definite proportions, constitutes pure air. But of these two gases each does not perform the same part in the function of respiration, nor is each equally necessary to the support of life.

If a living animal be placed in a vessel full of atmospheric air, and if all communication of the atmosphere with the vessel be prevented, the animal in a given time perishes. If an animal be placed in a vessel full of azote, after a given time it equally perishes; but if an animal be placed in a vessel full of oxygen, not only is the function of respiration carried on with far greater energy than in atmospheric air, but the animal lives a much longer time than in the same bulk of the latter fluid.

It is proved that no animal, from the lowest to the highest, is capable of sustaining life unless a certain proportion of oxygen be present in the fluid which it respires. Whether it breathe by the skin, by gills, or by lungs, whether the respiratory medium be water or air, the presence of oxygen is alike indispensable. Yet the life of no animal can be sustained by pure oxygen. If azote be not mixed with oxygen, evils are produced in the economy which sooner or later prove fatal. On the other hand, if the proportion of oxygen be diminished beyond a certain point, drowsiness, torpor, and death result. Not oxygen alone, then, but oxygen combined with azote, in the proportion in which nature has united these two fluids to form the atmosphere of the globe, is indispensable to animal existence.

When the same portion of atmospheric air is repeatedly respired by an animal, the oxygen contained in it gradually disappears, the gas lessening with every successive respiration, until at last so small a quantity remains that it is no longer capable of sustaining the life of an animal of that class. When respiration has deprived the air of its oxygen to such an extent, that it can no longer support animal life, the air is said to be consumed; but, correctly speaking, it is merely changed in composition, in the proportions in which its constituents are combined; consequently the effect of respiration is to alter the chemical composition of the air.

The essential change that takes place consists in the diminution of the oxygen and the increase of the carbonic acid. When inspired, atmospheric air goes to the lungs loaded with oxygen; when expired, it returns loaded with carbonic acid. That the air which returns from the lungs is loaded with carbonic acid, may be rendered manifest even to the eye. If a person breathe through a tube into water holding lime in solution, the carbonic acid contained in the expired air will unite with the lime and form a white powder analogous to chalk (carbonate of lime), which being insoluble, becomes visible.

On the other hand, the diminution of oxygen is demonstrated by chemical analysis. If 100 parts of atmospheric air be successively respired, until it is no longer capable of supporting life, and if it be then subjected to analysis, it is found that in place of being composed of 79 parts azote, 21 oxygen, and a variable quantity of carbonic acid, sometimes amounting to half a grain per cent., it consists of 77 parts azote, and 23 carbonic acid. The oxygen is gone, and is replaced by 23 parts of carbonic acid; at least this is the ordinary estimate; but different experimentalists differ somewhat in their account of the absolute quantity of oxygen that disappears, and of carbonic acid that is generated.

Whatever estimates of the oxygen consumed, and of the carbonic acid generated, be adopted, they can be taken only as medium quantities. Dr. Edwards demonstrated that the absolute quantity of oxygen consumed in a given time is constantly varying, not only in animals of different species, but even in the same animal under different circumstances; insomuch, that there are scarcely two hours in the day in which the same individual expends precisely the same quantity. The nature and degree of the exercise taken during the observation, the condition of the mind, the state of the health, the kind of food, the temperature of the air, and innumerable other causes materially influence the quantity of oxygen consumed. When, for example, the hourly consumption of oxygen, at the temperature of 54° Fahrenheit, amounted to 1345 cubic inches,* it fell, at the temperature of 79°, to 1210 cubic inches. During the process of digestion more is consumed than when the stomach is empty; more is required when the diet is animal than when it is vegetable, and more when the body and mind are active than when at rest.

With regard to the carbonic acid, Dr. Prout made the remarkable discovery, not only that the generation of this gas differs according to different circumstances, and more especially according to particular states of the system; but that the quantity of it which is produced regularly varies at particular periods of the day. The quantity generated is always more abundant during the day than during the night. About daybreak it begins to increase; continues to do so until noon, when it comes to its maximum, and then decreases until sunset. The maximum quantity generated at noon exceeds the minimum by about one-fifth of the whole. If from any cause the relative quantity be either increased or diminished above or below the ordinary maximum or minimum, it is invariably diminished or increased in an equal proportion during some subsequent diurnal period. The absolute quantity generated is materially diminished by the operation of any debilitating cause, such as low diet, protracted fasting, or long-continued exercise, depressing passions and the like. Few circumstances of any kind increase the quantity produced, and those only in a slight degree.

The changes produced by respiration on the other constituent of the air, azote, appear at first view to be extremely variable. By numerous and accurate experiments it is established that the quantity of this gas is at one time increased; at another diminished, and at another unchanged. It is probable that there is a constant absorption and exhalation of it; and that the apparent irregularity is the result of the preponderance of the one process over the other. When absorption preponderates, a smaller quantity is found in the air expired than in that inspired: when exhalation preponderates, a larger quantity is expired than inspired; and when the absorption and exhalation are equal, just as much is expired as inspired, and consequently there appears to be no absorption at all.

Such are the phenomena of respiration, as far as the labours of physiologists have succeeded in ascertaining them. But as the estimates of the quantity of air and blood contained in the lungs were rather matters of conjecture than of demonstration, and as the quantity of oxygen consumed, of carbonic acid generated, and of azote absorbed, appeared not to be determined with exactness, I requested Mr. Finlaison to apply his power of calculation to the investigation of this subject, taking as the basis of his calculations the facts positively and precisely ascertained by experiment and analysis. This he did with great care, and obtained the following results.

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* The ordinary consumption of oxygen is, for an adult, 1905 cubic inches per hour.

It was formerly estimated that the weight of pure atmospheric air is 305,000 grains troy for one million of cubic inches; but the latest authorities assign it to be 310,117 grains. Of this weight of one million of cubic inches of pure air,

The weight of the oxygen is . . .	71,809.3
The weight of the azote is . . .	238,307.7
Total	310,117.0

But common atmospheric air in its ordinary state contains in 1,000 cubic inches,

Of pure air	989
Of the vapour of water . . .	10
Of carbonic acid gas . . .	1

Ten inches of pure air are equal in weight to nine of oxygen.

Eight inches of azote are equal in weight to seven of oxygen.

The specific gravity of carbonic acid is to pure air at the rate of 15,277 to 10,000.

The specific gravity of the vapour of water is to pure air as 6,230 to 10,000. It follows that a million of cubic inches of air in its ordinary state weigh 309,111½ grains.

Carbonic acid gas is composed of oxygen and pure carbon in the proportion of eight grains of oxygen to three of carbon out of every eleven grains of carbonic acid.

Though during particular portions in the twenty-four hours, under circumstances which influence variously the actions of life, the quantity of the oxygen consumed, of carbonic acid generated, and of azote absorbed, vary, yet it is probable that the daily consumption, reproduction, and absorption of these gases, is pretty much the same one day with another. The experiments of Dr. Edwards clearly show that while these quantities vary to such an extent, when the observation embraces only a short interval, as to be scarcely ever the same hour by hour, yet that they lessen as the interval extends, until at length a nearly exact equilibrium is established.

Experimental philosophers have not obtained precisely the same results as to the quantities consumed and reproduced of these respective gases. At present, therefore, we can only approximate to the exact amount by taking the average of their observations. The following are the results of the principal experiments which have been instituted. The quantity of, oxygen consumed by an adult man in twenty-four hours is, according to

Menzes	51,840 cubic inches.
Lavoisier	46,048 ,,
Davy	45,504 ,,
Allen and Pepys . .	39,534 ,,

The mean of all which is, 45,731.5 inches.

In like manner the quantity of carbonic acid generated in the same time is, according to

Davy . .	38,304 cubic inches.
Allen and Pepys .	38,232 ,,
The mean of which is . .	38,268 ,,

The weight of 38,268 inches of carbonic acid gas is 18,130.1474 grains troy; and the weight of 45,731½ inches of oxygen is 15,757.9131 grains troy.

Now this weight of oxygen must have been derived from the decomposition of 221,882 cubic inches of common atmospheric air.

It has been shown that, in the state of health, one contraction of the heart propels to the lungs two ounces of blood; that this action of the heart is repeated 72 times in one minute; that to every four actions of the heart there is one action of respiration; that consequently there are 18 respirations in a minute, and 25,920 in the twenty-four hours.

From these premises it results that at each action of the heart there is decomposed of the air inspired, 8.5603 cubic inches, that is, a quarter of a pint within one-tenth of a cubic inch,—the quarter of a pint imperial measure being 8.6648 cubic inches.

Previous observation had assigned one pint as the volume of air ordinarily inhaled at a single inspiration. We now see that the quantity decomposed is a quarter of a pint. It is, then, true, that of the whole volume of air inspired, one-fourth part only is decomposed, and that three-fourths, after having been diffused through the air vesicles of the lungs, are expired without change.

Observation had also assigned 12 pints of air as the volume constantly present in the lungs,—that is, . . 415.9108 cubic inches.
The truth seems to be, that forty-eight times the quantity decomposed is constantly present, namely, ... 410.8926 cubic inches.
The difference is only . . . . . 4.0182 cubic inches,
which difference weighs less than 1¼ grains troy.

It is then concluded that the real contents of the lungs is a volume of 410.8926 cubic inches, which is exactly the 540th part of 221,882 cubic inches, being the whole volume decomposed in twenty-four hours. But 160 seconds is also exactly the 540th part of the number of seconds in twenty-four hours.

Of the whole weight of oxygen consumed in twenty-four hours . . . . 15,757.9131 grains,
the 540th part, or the proportion
of 160 seconds, is . . . . 29.18132 ,,
and 410.8926 cubic inches of atmospheric air, which, as above, is the contents of the lungs, contain of
oxygen the same weight . . . . . . 29.18132 ,,

Then, if respiration were suddenly stopped, provision is made by the quantity of air always retained in the lungs for the oxygenation of the blood while flowing at the ordinary rate of 72 strokes per minute, for the exact space of 160 seconds, and for not one instant longer.

This interval of time, then, as has been stated, is very probably the time in which the blood performs one circuit, not 150 seconds. Then 540 circuits are performed in the twenty-four hours, or 3 circuits in every eight minutes. From this estimate has been deduced the quantity of blood contained in the whole body of the human adult.

The air inspired in twenty-four hours contains as under :—

	Bulk in cubic inches.	Weight in grains troy.	Ingredients.
Undecomposed, and to be returned unchanged . . .	665,646	205,758.833,	Common air,
To be decomposed, containing in solution			
Pure atmospheric air . . .	219,441	15,757.913, 52,294.509,	Oxygen, Azote,
Vapour of water	2,219	428.726,	Vapour,
Carbonic acid gas	222	105.130,	Carbonic Acid,
Total	887,528	274,345.111,	Of all kinds.

This is, in bulk, 25,607¼ imperial pints, or 57 hogsheads 1 gallon and 7¼ pints, and in weight 571½ ounces and 25 grains.

Now, although the air expired, in consequence of its recomposition, may have undergone changes in bulk, yet it seems agreeable to all analogy to suppose that its weight will remain the same as the weight inhaled. This, however, is not asserted as a truth, but only assumed, in order to show the result of such a theory.

Then the air expired in twenty-four hours will be as follows :—

	Bulk in cubic inches.	Weight in grains troy.
Given out undecomposed as before .	665,646	205,758.833
Recomposed carbonic acid gas . .	38,268	18,130.147
Azote liberated.	165,927	50,027.405
Vapour of water as before . . .	2,219	428.726
Total . . .	872,060	274,345.111

weighing as before, but less in bulk by 446¼ pints: so that for every 100,000 inches expired there were inspired 101,774 cubic inches.

	Grains.
When from the weight of carbonic acid gas thus expired, viz.,	18,130.147
we deduct the small portion inhaled in solution with the air	105.130
The remainder is	18,025.017
The constituent parts of which are oxygen derived from the air	13,109.104
And pure carbon derived from the blood being the difference	4,915.913

Thus in the compass of twenty-four hours the blood has produced 10 ounces and 116 grains very nearly of pure carbon.

	Grains.
Now, from the oxygen consumed in twenty-four hours as above	15,757.913
Deduct the weight restored in the form of carbonic acid gas	13,109.104
The remainder must have been absorbed into the blood	2,648.809
But the weight of carbon given out being as above	4,915.913
There is still an excess given out weighing	2,267.104

Some azote, however, is absorbed into the blood as well as the above ascertained quantity of oxygen.

The weight of azote so absorbed must be precisely	2,267.104
f the theory be true, that equal weights are expired and inspired. In which case, as the weight of the azote of the air inspired was, as shown above	52,294.509
While the azote expired could only have weighed	50,027.405
The difference would have been absorbed	2,267.104

And thus the weight of carbon discharged by the blood is precisely ompensated by the united weight of the oxygen and azote which it as absorbed.

Since it appears to be a general truth that one quarter of the air espired is decomposed, and that the volume of air continually present n the lungs is sufficient for that consumption of oxygen which is equisite in 160 seconds of time, *if that volume be*, as is apparent, 8 *times the quantity decomposed* out of a single respiration, no error n the quantity of oxygen consumed in the twenty-four hours, which e have assumed, will affect the time of 160 seconds. For there being 8 × 60 × 24 respirations, and 60 × 60 × 24 seconds of time in the twenty-four hours, the 48th part of the first, and the 160th part of the last product is equally the 540th part of the whole, whatever it may be.

But if the time in which a circuit of the blood is performed be, as is most evident, identical with the time in which the whole volume of air in the lungs is decomposed, and if such period of time were, as the old observers have assigned, 150 seconds, then it would follow that only 45 times the quantity of air decomposed at a breath is present in the lungs, amounting to 385¼ cubic inches, and that the whole blood in the body is 24 ounces less than on the supposition of 160 seconds, that is to say, only 360 ounces, or 22½ pounds avoirdupois. Because the 45th part of 18 × 60 × 24 is the same as the 150th part of 60 × 60 × 24; in each it is the 567th part of the whole.

From the whole of these observations and calculations the following general results are deduced:—

1. The volume of air ordinarily present in the lungs is very nearly twelve pints.
2. The volume of air received by the lungs at an ordinary inspiration is one pint.
3. The volume of air expelled from the lungs at an ordinary expiration is a very little less than one pint.
4. Of the volume of air received by the lungs at one inspiration, only one-fourth part is decomposed at one action of the heart.
5. The fourth part of the volume of air received by the lungs at one inspiration, and decomposed at one action of the heart, is so decomposed in the five-sixth parts of one second of time.
6. The time in which a circuit of blood is performed is identical with the time in which the whole volume of air in the lungs is decomposed.
7. The whole volume of air decomposed in twenty-four hours is 221,882 cubic inches, exactly 540 times the volume of the contents of the lungs; 160 seconds being also exactly the 540th part of the number of seconds in twenty-four hours.
8. The quantity of the blood that flows to the lungs to be acted upon by the air at one action of the heart is two ounces.
9. This quantity of blood is acted upon by the air in the five-sixth parts of one second of time.
10. One circuit of the blood is performed in 160 seconds of time. Three circuits are performed every eight minutes; 540 circuits are performed in the twenty-four hours.
11. The quantity of blood in the whole body of the human adult is 24 pounds avoirdupois, or 20 pints imperial measure.
12. In the space of twenty-four hours, 57 hogsheads of air flow to the lungs.

13. In the same space of time 24 hogsheads of blood are presented in the lungs to this quantity of air.

14. In the mutual action that takes place between these quantities of air and blood, the air loses 15,757.9131 grains, or 328¼ ounces of oxygen, and the blood 10 ounces and 116 grains of carbon.

15. The blood, while circulating through the lungs permanently retains and carries into the system—of oxygen, 2,648,809 grains; and of azote, 2,267,104 grains.

16. The ultimate results are two:—

1st. While the chemical composition of the blood is essentially changed, its weight amidst all these complicated actions is maintained steadily the same; for the weight of carbon which is discharged by the blood is precisely compensated by the united weight of the oxygen and azote which it absorbs.

2ndly. The distribution of quantities is universally by proportions or multiples. Thus, of the air inspired, one measure is decomposed and three measures are returned unchanged: of the air decomposed at a single inspiration, there are always in store in the lungs precisely forty-eight measures; and so on in many other cases. The proportions are not arithmetical, but geometrical. When we compare arithmetical quantities with each other, we say that one quantity is by so much greater than another; when we compare geometrical quantities, we say that one quantity is so many times greater than another. From this adoption in the distribution of quantities of geometrical proportions it results that whatever be the size of the animal the ratios remain uniformly the same, and that thus one and the same law is adapted to the vital agencies of living beings under every possible diversity of magnitude and circumstance.

Such are the interesting and important properties and relations deducible from the phenomena of respiration. The disappearance of oxygen and azote from the air inspired, and the replacement of the oxygen that disappears by the production of carbonic acid, and of the azote by the exhalation of azote, in which, as we have seen, the great changes wrought by respiration on the air consist, are essentially the same in all animals, whatever the medium breathed, and whatever the rank of the animal in the scale of organization. In all, the proportion of the oxygen of the inspired air is diminished;—in all, carbonic acid gas is produced. Comparing, then, the ultimate result of the function of respiration in the two great classes of living beings, it follows that the plant and the animal produce directly opposite changes in the chemical constitution of the air. The carbonic acid produced by the animal is decomposed by the plant, which retains the carbon in its own system and returns the oxygen to the air. On the other hand, the oxygen evolved by the plant is absorbed by the animal, which in its turn exhales carbonic acid for the reabsorption of the plant.

Thus the two great classes of organized beings renovate the air for each other, and maintain it in a state of perpetual purity. The plant, it is true, absorbs oxygen during the night as well as the animal; but the quantity which it gives off in the day more than compensates for that which it abstracts in the absence of light. This interesting fact was established by an extended series of experiments instituted by Professor Daubeney* for the express purpose of investigating this point.

From the general tenor of these experiments, it appears that, in fine weather and as long as the plant is healthy, it adds to the atmosphere an amount of oxygen not only sufficient to compensate for the quantity it abstracts in the absence of light, but to counterpoise the effects produced by the respiration of the whole animal kingdom. The result of one of these experiments will convey some conception of the amount of oxygen evolved. A quantity of leaves about fifty in number were enclosed in a jar of air; the surface of all the leaves taken together was calculated at about three hundred square inches; by the action of these leaves on the carbonic acid introduced into the jar, there was added to the air contained in it no less than twenty-six cubic inches of oxygen. As there was reason to conclude that the evolution of oxygen, in the circumstances under which this experiment was performed, was considerably less than it would have been in the open air, several plants were introduced into the same jar of air in pretty quick succession: the amount of oxygen now evolved was increased from twenty-one to thirty-nine per cent., and probably had not even then attained the limit to which the increase of this constituent might have been brought. From the proportions of the constituent elements of carbonic acid gas it necessarily follows that, by the mere process of decomposition, out of every eleven grains of carbonic acid gas eight grains of oxygen must be liberated, three grains of carbon being retained by the plant, and consequently that eight grains of oxygen must be restored to the atmosphere, less only by so much as the plant itself may absorb. How great, then, must be the production of oxygen by an entire tree under favourable circumstances; that is, when animal respiration and animal putrefaction present to it an abundant supply of carbonic acid on which to act!

This influence, says Professor Daubeney, is not exerted exclusively by plants of any particular kind or description. I have found it alike in the monocotyledonous and dycotyledonous; in such as thrive in sunshine and those which prefer the shade; in the aquatic as well as in those of a more complicated organization. How low in the scale of vegetable life this power extends is not yet exactly ascertained; the point at which it stops is probably that at which there ceases to be leaves.

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* "On the Action of Leaves upon Plants, and of Plants upon the Atmosphere." By Charles Daubeney, M.D., F.R.S., Professor of Chemistry and Botany in the University of Oxford. Philosophical Transactions of the Royal Society of London, for the year 1836. Part I.

From the whole, then, it appears that the functions of the plant have a strict relation to those of the animal; that the plant, created to afford subsistence to the animal, derives its nutriment from principles which the animal rejects as excrementitious, and that the vegetable and animal kingdoms are so beautifully adjusted, that the very existence of the plant depends upon its perpetual abstraction of that, without the removal of which the existence of the animal could not be maintained.

The changes produced upon the blood by the action of respiration are no less striking and important than those produced upon the air. The blood contained in the pulmonary artery, venous blood, is of a purple or modena red colour: the moment the air transmitted to the blood by the bronchial tubes comes into contact with it, in the rete mirabile, this purple blood is converted into blood of a bright scarlet colour. Precisely the same change is produced upon the blood by its contact with the air out of the body. If a clot of venous blood be introduced into a vessel of air, the clot speedily passes from a purple to a scarlet colour; and if the air contained in the vessel be analysed, it is found that a large portion of its oxygen has disappeared, and that the oxygen is replaced by a proportionate quantity of carbonic acid. If the clot be exposed to pure oxygen, this change takes place more rapidly and to a greater extent; if to air containing no oxygen, no change of colour takes places.

The elements of the blood upon which a portion of the air exerts its action are carbon and hydrogen. The oxygen of the air unites with the carbon of the blood and forms carbonic acid, and this gas is expelled from the system by the action of expiration. The constituent of the blood which affords carbon to the air would appear to be chiefly the red particles. The other portion of the oxygen of the air unites with the hydrogen which is expelled with the carbonic acid in the form of aqueous vapour. The direct and immediate effect of the action of respiration upon the blood is then to free it from a quantity of carbon and hydrogen.

Physiologists are not agreed whether the union of the oxygen of the air with the carbon of the blood takes places in the lungs or in the system. Some experimentalists maintain that the oxygen which disappears from the air, and that which is contained in the carbonic acid, are exactly equivalent, so that no oxygen can be absorbed. According to this view, which has been clearly shown to be incorrect, the effect of respiration is merely to burn the carbon of the blood, just as the oxygen of the air burns wood in a common fire, the result of this combustion being the generation of carbonic acid, which is expelled from the system the moment it is formed.

The theory of Dr. Crawford is essentially the same, which supposes that venous blood contains a peculiar compound of carbon and hydrogen, termed *hydro-carbon*, the elements of which unite in the lungs with the oxygen of the air, forming water with the one and carbonic acid with the other. Mr. Cooper taught the same doctrine in his lectures, without any knowledge of the fact that Crawford had suggested a similar modification of his theory.

It is now established that more oxygen disappears than is accounted for by the amount of carbonic acid that is generated. The experiments of Dr. Edwards had already shown this in so decisive a manner that physiologists almost universally admitted it as an ascertained fact. The calculations of Mr. Finlaison, to whom the opinions of physiologists on this point were unknown, determined the precise amount of oxygen, and the probable amount of azote absorbed. By many physiologists it is supposed that the oxygen retained by the lungs, as long as it remains in this organ, enters only into a state of loose combination with the blood; that in this state of loose combination, it is carried from the lungs into the general system; and that it is only in the system that the union becomes intimate and complete. According to this view, the lungs are merely the portal by which the substances employed in respiration are received and discharged, the essential changes induced taking place in the system. That it is through the lungs that the oxygen required by the system is received, is an opinion founded on experiments no less exact than decisive; it is in accordance with the most probable theory of the production and distribution of animal heat (chap. xiii.); and the preponderance of evidence in its favour is so great that, in the present state of our knowledge, it may be considered as established; but it will appear hereafter that the lungs are by no means passive in the process, and that, physiologically considered, they as truly constitute a gland secreting carbonic acid gas as the liver is a gland secreting bile.

Such are the main facts which have been ascertained relative to respiration, as far as this function is performed by the lungs. But the liver is a respiratory organ as well as the lungs. It decarbonizes the blood. It carries on this process to such an extent, that some physiologists are of opinion that the liver is the chief organ by which the decarbonization of the blood is effected. The following considerations show that whatever be the relative amount of its action, the liver powerfully co-operates with the lungs in the performance of a respiratory function.

1. The liver, like the lungs, is a receptacle of venous blood; blood

loaded with carbon. The great venous trunk which ramifies through the lungs is the pulmonary artery, containing all the blood which has finished its circuit through the system. The great venous trunk which ramifies through the liver is the vena portæ, containing all the blood which has finished its circuit through the apparatus of digestion. The liver is a secreting organ, distinguished from every other secreting organ by elaborating its peculiar secretion from venous blood. Carbon is abstracted from the venous blood that flows through the lungs in the form of carbonic acid; carbon is abstracted from the venous blood that flows through the liver in the form of bile.

2. All aliment, but more especially vegetable food, contains a large portion of carbon, more it would appear than the lungs can evolve. The excess is secreted from the blood by the liver, in the form of resin, colouring matter, fatty matter, mucus, and the principal constituents of the bile. All these substances contain a large proportion of carbon. After accomplishing certain secondary purposes in the process of digestion, these biliary matters, loaded with carbon, are carried out of the system together with the non-nutrient portion of the aliment. In the decarbonizing process performed by the lungs and the liver, the chief difference would seem, then, to be in the mode in which the carbon that is separated is carried out of the system. In the lungs it is evolved, as has been stated, in union with oxygen in the form of carbonic acid; in the liver, in union with hydrogen in the form of resin and fatty matter.

3. Accordingly, in tracing the organisation of the animal body from the commencement of the scale, it is found that among the distinct and special organs that are formed, the liver is one of the very first. It would appear to be constructed as soon as the economy of the animal requires a higher degree of respiration than can be effected by the nearly homogeneous substance of which, very low down in the scale, the body is composed. Invariably through the whole animal series, the magnitude of the liver is in the inverse ratio to that of the lungs. The larger, the more perfectly developed the lungs, the smaller the liver; and conversely, the larger the liver the smaller and the less perfectly developed the lungs. This is so uniform that it may be considered as a law of the animal economy. In the highly organised warm-blooded animal, with its large lungs, divided into numerous lobes, and each lobe composed of minute vesicles respiring only air, the magnitude of the liver compared with that of the body is small. In the less highly organised animal of the same class, with its smaller and less perfectly developed lung, respiring partly air and partly water, the liver increases as the lung diminishes in size. In the reptile with its little vesicular lung, divided into large cells, the liver is proportionally of greater magnitude. In the fish which has no lung, but

which respires by the less highly organised gill, and only in the medium of water, the proportionate size of the liver is still greater; but in the molluscous animal, in which the lung or the gill is still less perfectly developed, the bulk of the liver is prodigious.

4. In all animals the quantity of venous blood which is sent to the liver increases, as that transmitted to the lung diminishes. In the higher animal the great venous trunk which ramifies through the liver (the vena portæ) is formed by the veins of the stomach, intestines, spleen, and pancreas, which are the only organs that transmit their blood to the liver. In the reptile, besides all these organs, the hind legs, the pelvis, the tail, the intercostal veins forming the vena azygos, and in some orders of this class, even the kidneys also send their blood to the liver; but in the fish, in addition to all the preceding organs, the apparatus of reproduction likewise transmits its blood to the liver. The very formation of the venous system in the different classes of animals seems thus to point to the liver as a compensating and supplementary organ to the lung.

5. The permanent organs in the lower animal are a type of the transitory forms through which the organs of the higher animal pass in the progress of their growth. Thus the liver of the human fœtus is of such a disproportionate size, as to approximate it closely to that of the fish or of the reptile. After the birth of the human embryo, respiration is effected in part by the lung; but before birth the lung is inactive, no air reaches it; it contributes nothing to respiration; the decarbonising action of the blood is accomplished, not by the lung, but by the liver; hence the prodigious bulk of the fœtal liver and its activity in the secretion of bile, and especially towards the latter months of pregnancy, when all the organs are greatly advanced in size and completeness.

6. Pathology confirms the evidence derived from comparative anatomy and physiology. When the function of the lung is interrupted by disease, the activity of the liver is increased. In inflammation of the lung (pneumonia); in the deposition of adventitious matter in the lung (tubercles), by which the air vesicles are compressed and obliterated, the lung loses the power of decarbonizing the blood in proportion to the extent and severity of the disease with which it is affected. In this case the secretion of bile is increased. In diseases of the heart the liver is enlarged. In the morbus cæruleus the liver retains through life its fœtal state of disproportion.

7. In the last place, there is a striking illustration of the respiratory action of the liver, in the vicarious office which it performs for the lung, during the heat of summer in cold, and all the year round in hot climates. In the heat of summer, and more especially in the intense and constant heat of a warm climate, in consequence of the rarefaction

of the air, respiration by the lung is less active and efficient than in the winter of the cold climate. During the exposure of the body to this long-continued heat, there is a tendency to the accumulation of carbon in the blood. An actual accumulation is prevented, by an increased activity in the secretion of bile, to which the liver is stimulated by the heat. In order to obtain the material for the formation of this unusual quantity of bile, it abstracts carbon largely from the blood; to this extent it compensates for the diminished efficiency of the lung, and thus removes through the vena portæ that superfluous carbon which would otherwise have been excreted through the pulmonary artery.

Taking life in its most extended sense, as comprehending both the circles it includes, the organic and the animal, it may be said to have three great centres, of which two relate to the organic, and the third to the animal life. The two centres which relate to the organic life are the systems of respiration and circulation; the third, which relates to the animal life, is the nervous system. Of the organic life, the lungs and the heart are the primary seats; of the animal, the brain and the spinal cord. Between each the bond of union is so close, that any lesion of the one influences the other, and neither can exist without the support of all. They form a triple chain, the breaking of a single link of which destroys the whole.

But of these three great centres of life, upon which all the other vital phenomena depend, the most essential is respiration; hence, to consider the relation of this function to the others, is to take the most comprehensive view of the uses which respiration serves in the economy.

The first and most important use of the function of respiration is to maintain the action of the organs of the animal life. It has been shown that the organic is subservient to the animal life, and that to build up the apparatus of the latter, and to maintain it in a condition fit for performing its functions, is the final end of the former. The direct and the immediate effect of the suspension of respiration is the abolition of both functions of the animal life—sensation and voluntary motion. If a ligature be placed around the trachea of a living animal so as completely to exclude all access of air to the lungs, and if the carotid artery be then opened, and the blood allowed to flow, the bright scarlet-coloured blood contained in the artery is observed gradually to change to a purple hue. The exact point of time at which this change begins may be noted. It is seen to assume a darker tinge at the end of half a minute; at the end of one minute its colour is still darker, and at the end of one minute and a half, or at most two minutes, it is no longer possible to distinguish it from venous blood. As soon as this change of colour begins to be visible the animal becomes uneasy; his agitation increases as the colour deepens; and when it becomes completely dark, that instant the animal falls down insensible. If in this state of insensibility air be readmitted to the lungs, the dark colour of the blood rapidly changes to a bright scarlet, and instantly sensation and consciousness return. But if, on the contrary, the exclusion of the air be continued for the space of three minutes from the first closing of the trachea, the animal not only remains to all appearance dead, but in general no means are capable of recovering him from the state of insensibility; and if the exclusion of the air be protracted to four minutes, apparent passes into real death, and recovery is no longer possible. It follows that one of the conditions essential to the exercise of the function of the brain is, that this organ receive a due supply of arterial blood.

The second use of the function of respiration is to afford blood capable of maintaining the muscles in a condition fit for the performance of their peculiar office, that of contractility. The closure of the trachea not only abolishes sensation, but the power of voluntary motion: sensation and motion are lost at once: on the readmission of air to the lungs, both functions are regained at once: it follows that the process of respiration is as essential to the action of the muscle as to that of the brain. "By arterial blood," says Young, "the muscles are furnished with a store of that unknown principle by which they are rendered capable of contracting." "The oxygen absorbed by the blood," says Spallanzani, "unites with the muscular fibres and endows them with their contractility." It is more correct to say, respiration takes carbon from the blood and gives it oxygen, and by this means endows the blood with the power of maintaining the contractility of the muscular fibre.

But respiration is as essential to the action of the organs of the organic life as to those of the animal. In a short time after the respiration ceases, the circulation stops. When the blood is no longer changed in the lungs, it soon loses all power of motion in the system; because venous blood paralyses the muscular fibres of the heart as of the arm. When the left ventricle of the heart sends out venous blood to the system, it propels it into its own nutrient arteries, as well as into the other arteries of the body; into the coronary arteries, as well as into the other branches of the aorta. The heart loses its contractility for the same reason as every muscle under the like privation; because venous instead of arterial blood flows in its nutrient arteries; and the circulation stops when the heart is no longer contractile, because the engine is destroyed that works the current.

Venous blood consists of chyle, the nutritive fluid formed from the aliment; of lymph, a fluid composed of organic particles, which, having already formed an actual part of the solid structures of the body, are now returning to the lungs to receive a higher elaboration; and of blood which, having completed its circuit through the system, and there given off its nutrient and received excrementitious matter, is now returning to the lungs for depuration and renovation. These commingled fluids, on parting in the lungs with carbonic acid and water, and on receiving in return oxygen and azote, are converted into arterial blood; that is, blood more coagulable than venous, and richer in albumen, fibrin, and red particles, the proximate organic principles of all animal structures. The rich and pure stream thus formed is sent out to the various tissues and organs, from which, as it flows to them, they abstract the materials adapted to their own peculiar form, composition, and vital endowments. By the reception of these materials the organs are rendered capable of performing the vital actions which it is their office to accomplish. And thus the processes of digestion, absorption, secretion, nutrition, formation, reproduction—all the processes included in the great organic circle, no less than muscular action and nervous energy—depend on receiving a due supply of arterial blood. All these actions, like the faculties of the animal life, cease totally and for ever in a few minutes after the formation of this vital fluid has been stopped by the suspension of respiration.

In the last place, the depurating process effected by respiration is necessary to prevent the decomposition of the blood, and eventually that of the body. The first step in the spontaneous decomposition of animal matter consists in the loss of a portion of its carbon, which, uniting with the oxygen of the atmosphere, forms carbonic acid; precisely the same thing that takes place in the process of respiration. The bodies of all animals, of worms, insects, fishes, birds, and mammalia, deoxidate the air and load it with carbonic acid after death, some of them nearly as much as during life; and this before any visible marks of decomposition can be traced. It is probable that the cause which more immediately operates in preventing the decomposition of the body is the abstraction of a part of the carbon of the blood; that were these carbonaceous particles allowed to accumulate, they would produce a tendency to decomposition, which would terminate in complete disorganisation; and consequently, that one main object of the process of respiration is to afford blood not only capable of nourishing and sustaining the organs, but of maintaining their integrity, by removing noxious matter, the presence of which would subvert their composition and lead to their entire decomposition.

The ultimate object of respiration, then, is to prepare and to preserve in a state of purity a fluid capable of affording to all the parts of the body the materials necessary to maintain their vital endowments. By the exhalation of oxygen and water, and the absorption of carbon, under the agency of light, the plant elaborates such a fluid from its nutritive sap, and out of this elaborated sap forms ternary combinations, the organic elements of all vegetable solids. By the absorption of oxygen and azote, and the exhalation of carbonic acid and water, probably under the influence of electricity, conducted and regulated by the nervous system, the animal elaborates such a fluid from its aliment, and out of this elaborated fluid forms quaternary combinations, albumen, and fibrin, the organic elements of all animal solids.

CHAPTER XIII.

Of the temperature of living bodies—Temperature of plants—Power of plants to resist cold and endure heat—Power of generating heat—Temperature of animals—Warm-blooded and cold-blooded animals—Temperature of the higher animals—Temperature of the different parts of the animal body—Temperature of the human body—Power of maintaining that temperature at a fixed point whether in intense cold or intense heat—Experiments which prove that this power is a vital power—Evidence that the power of generating heat is connected with the function of respiration—Analogy between respiration and combustion—Phenomena connected with the functions of the animal body, which prove that its power of generating heat is proportionate to the extent of its respiration—Theory of the production of animal heat—Influence of the nervous system in maintaining and regulating the process—Means by which cold is generated, and the temperature of the body kept at its own natural standard during exposure to an elevated temperature.

Closely connected with the function of respiration, is the power which all living beings possess of resisting within a certain range the influence of external temperature. The plant is warmer than the surrounding air in winter, and colder in summer. A thermometer placed at the bottom of a hole bored into the centre of a living tree, precaution being taken to keep off as much as possible all external influence either of heat or cold, does not rise and fall according to the changes of external temperature; but rises when the external air is cold, and falls when it is warm. Thus, in a cold day in spring, the wind being north, at six o'clock in the evening, the temperature of the external air being 47°, that of a tree was 55°. On another cold day in the same month, there being snow and hail, and the wind in the north-east, at six o'clock in the evening, the external temperature being 39°, that of the tree was 45°. On the contrary, in one experiment, when the temperature of the air was 57½°, that of the tree was only 55°; and when the temperature of the air was 62°, that of the tree was 56°.

These experiments afford an explanation of circumstances familiar to common observation. Every one has noticed that the snow which falls on grass and trees melts rapidly, while that on the adjoining gravel walks often remains a long time unthawed. Moist dead sticks are constantly found frozen hard in the same garden with tender growing twigs, which are not in the least degree affected by the frost. Every winter in our own climate tender herbaceous plants resist degrees of cold which freeze large bodies of water.

But the colder, and the warmer the climate, the more strikingly does the plant exemplify the power with which it is endowed of resisting external temperature. In the northern parts of America the temperature is often 50° below zero; yet, though exposed to this intense degree of cold, the spruce fir, the birch, the juniper, &c., preserve their vitality uninjured. From numerous experiments which have been performed expressly with a view to ascertain this point, it is found that a plant which has been once frozen is invariably dead when thawed. It is also proved by direct experiment, that if the sap be removed from its proper vessels, it freezes at 32°, the ordinary freezing point. In the northern parts of America, then, the plant must preserve in its living vessels its sap from freezing, when exposed to a temperature of 50° below zero; which sap out of these vessels would congeal at the ordinary freezing point; that is, the plant of this climate is endowed with the power of resisting a degree of cold ranging from the ordinary freezing point to 50° below zero; a property which can be referred only to a vital power, by the operation of which the plant generates within itself a degree of heat sufficient to counteract the external cold.

The opposite faculty of resisting the influence of external heat is exemplified by the trees and shrubs of tropical climates, often surrounded by a temperature of 104°, which they resist just as the plant of the northern clime resists the intense degrees of cold to which it is exposed.

That the plant is endowed with the power of generating heat is demonstrated by the phenomena which attend the performance of some of its vital processes, such as those of germination and flowering. During the germination of barley, the thermometer was observed to rise in the course of one night to 102°. The bulb of a thermometer applied to the surface of the spadix of an arum maculatum, indicated a temperature 7° higher than that of the external air; but in an arum cordifolium, at the Isle of France, a thermometer placed in the centre of five spadixes stood at 111°; and in the centre of twelve at 121°, though the temperature of the external air was only 66°.

Animals indicate in a still more striking degree the power of generating heat. The lower the animal in the scale of organisation, indeed, the nearer it approaches to the plant in the comparative feebleness of this function. The heat of worms, insects, crustacea, mollusca, fishes, and amphibia, is commonly only two or three degrees above that of the medium in which they are immersed. Absolutely colder than the higher animals, they are at the same time incapable of resisting any considerable changes in the temperature of the surrounding medium, whether from heat to cold or from cold to heat. The higher animals, on the contrary, maintain their heat steadily at a fixed point, or very nearly at a fixed point, however the temperature of the surrounding medium may change. Hence animals are divided into two great classes, the cold-blooded and the warm-blooded. The temperature of the cold-blooded is lower than that of the warm-blooded, and it varies with the heat of the surrounding medium; the temperature of the warm-blooded is higher than that of the cold-blooded, and it remains nearly at the same fixed point, however the heat of the surrounding medium may change.

The temperature natural to the higher animals differs somewhat according to their class. The temperature of the bird is the highest, and is pretty uniformly about 103° or 104°; that of the mammiferous quadruped is 100° or 101°; that of the human species is 97° or 98°.

The temperature of the animal body is not precisely the same in every part of it. The ball of the thermometer introduced within the rectum of the dog stood at 100½°; within the substance of the liver at 100¾°; within the right ventricle of the heart at 101°, and within the cavity of the stomach at 101°. In the brain of the lamb it stood at 104°; in the rectum at 105°; in the right ventricle of the heart, and in the substance of the liver and of the lungs, at 106°; and in the left ventricle of the heart at 107°.

The temperature natural to the human body is 98°. When the human body is surrounded by an atmosphere at the temperature of 30°, it must have its heat rapidly extracted by the cold medium; yet the temperature of the body, however long it remain exposed to such a degree of cold, does not sink, but keeps steadily at its own standard. But animals which inhabit the polar regions are often exposed to a cold 40° below zero. The temperature of Melville Island is so low during five months of the year that mercury congeals, and the temperature is sometimes 46° below zero; yet the musk oxen, the rein deer, the white hares, the polar foxes, and the white bears which abound in it maintain their temperature steadily at their own natural standard.

The power which the higher animal possesses of resisting heat is still more remarkable than its power of resisting cold. On taking rabbits and guinea-pigs from the temperature of 50°, and introducing them very rapidly to the temperature of 90°, it was found that the animals acquired only two or three degrees of heat. How different the result when the cold-blooded animal is subjected to the same experiment! The temperature of the surrounding air being 45°, a thermometer introduced into the stomach of a frog rose to 49°. The frog being then put into an atmosphere made warm by heated water, and allowed to stay there twenty minutes, the thermometer on being now introduced into the stomach rose to 64°.

But the human body may be actually placed in a temperature of 60° above that of boiling water, not only without sustaining the slightest injury, but without having its own temperature raised excepting by two or three degrees. The attention of physiologists was first directed to this curious fact by some remarkable circumstances related by the servants of a baker at Rochefoucault, who were in the habit of going into the heated ovens in order to prepare them for the reception of the loaves. In performing this service, the young women were sometimes exposed to a temperature as high as 278°. It was stated that they could endure this intense heat for twelve minutes, without any material inconvenience, provided they were careful not to touch the surface of the oven. Subsequently Drs. Fordyce, Blagden, and others, with a view to ascertain the exact facts, entered a chamber, heated to a temperature much above that of boiling water, and some of the phenomena observed during these experiments are highly curious.

In the first room entered by these experimentalists, the highest thermometer varied from 132° to 130°; the lowest stood at 119°. Dr. Fordyce having undressed in an adjoining cold chamber, went into the heat of 119°; in half a minute the water poured down in streams over his whole body, so as to keep that part of the floor where he stood constantly wet. Having remained here fifteen minutes, he went into the heat of 130°; at this time the heat of his body was 100°, and his pulse beat 126 times in a minute. While Dr. Fordyce stood in this situation a Florence flask was brought in by his order, filled with water heated to 100°, and a dry cloth, with which he wiped the surface of the flask quite dry; but it immediately became wet again, and streams of water poured down its sides, which continued till the heat of the water within had risen to 122°, when Dr. Fordyce went out of the room, after having remained fifteen minutes in a heat of 130°: just before he left the room his pulse made 129 beats in a minute; but the heat under his tongue and in his hand did not exceed 100°.

In a subsequent experiment the chamber was entered when the thermometer stood above 211°. The air heated to this degree, says Dr. Blagden, felt unpleasantly hot; but was very bearable. Our most uneasy feeling was a sense of scorching in the face and legs; our legs particularly suffered very much, by being exposed more fully than any other part to the body of the stove, heated red hot by the fire within. Our respiration was not at all affected; it became neither quick nor laborious; the only difference was a want of that refreshing sensation which accompanies a full inspiration of cool air. But the most striking effects proceeded from our power of preserving our natural temperature. Being now in a situation in which our bodies bore a very different relation to the surrounding atmosphere from that to which we had been accustomed, every moment presented a new phenomenon. Whenever we breathed on a thermometer, the quicksilver sank several degrees. Every expiration, particularly if made with any degree of violence, gave a very pleasant impression of coolness to our nostrils, scorched before by the hot air rushing against them whenever we inspired. In the same manner our now cold breath agreeably cooled our fingers whenever it reached them. Upon touching my side, it felt cold like a corpse; and yet the actual heat of my body, tried under my tongue, and by applying closely the thermometer to my skin, was 98°, about a degree higher than its ordinary temperature. When the heat of the air began to approach the highest degree which this apparatus was capable of producing, our bodies in the room prevented it from rising any higher; and when it had been previously raised above that point, invariably sunk it. Every experiment furnished proofs of this. Mr. Banks and Dr. Solander each found that his single body was sufficient to sink the quicksilver very fast, when the room was brought nearly to its maximum of heat.

In a third series of experiments the temperature of the chamber was raised to the 260th degree. At this time, continues Dr. Blagden, I went into the room, with the addition to my common clothes of a pair of thick worsted stockings drawn over my shoes, and reaching some way above my knees. I also put on a pair of gloves, and held a cloth constantly between my face and the stove (necessary precautions against the scorching of the red-hot iron). I remained eight minutes in this situation, frequently walking about to all the different parts of the room, but standing still most of the time in the coolest spot near the lowest thermometer. The air felt very hot, but by no means so as to give pain. I had no doubt of being able to bear a much greater heat; and all who went into the room were of the same opinion. I sweated, but not very profusely. For seven minutes my breathing remained perfectly good; but after that time, I began to feel an oppression in my lungs, attended with a sense of anxiety; which gradually increasing for the space of a minute, I thought it most prudent to end the experiment. My pulse, counted as soon as I came into the cool air, for the uneasy feeling rendered me incapable of examining it in the room, beat at the rate of 144 pulsations in a minute, which is more than double its ordinary quickness. In the course of this experiment, and others of the same kind by several of the gentlemen present, some circumstances occurred to us which had not been remarked before. The heat, as might have been expected, felt most intense when we were in motion; and on the same principle, a blast of the heated air from a pair of bellows was scarcely to be borne: the sensation in both these cases exactly resembled that felt in our nostrils on inspiration. It was observed that our breath did not feel cool to our fingers unless held very near the mouth; at a distance the cooling power of the breath did not sufficiently compensate the effect of putting the air in motion, especially when we breathed with force.

On going undressed into the room, the impression of the air was much more disagreeable than before; but in five or six minutes, a profuse sweat broke out, which instantly relieved me. During all the experiments of this day, whenever I tried the heat of my body, the thermometer always came very nearly to the same point (the ordinary standard), not even one degree of difference, as in our former experiments.

To prove that there was no fallacy in the degree of heat shown by the thermometer, but that the air which we breathed was capable of producing all the well-known effects of such heat on inanimate matter, we put some eggs and a beef-steak upon a tin frame, placed near the standard thermometer, and farther distant from the stove than the wall. In about thirty minutes the eggs were taken out roasted quite hard. In about forty-seven minutes the steak was not only dressed, but almost dry. Another beef-steak was rather overdone in thirty-three minutes. In the evening when the heat was still greater, we blew upon a third steak with the bellows, which produced a visible change on its surface, and hastened its dressing; the greatest part of it was pretty well done in thirteen minutes.

The human body, then, may be exposed to a temperature of 50° below zero, without having its own heat appreciably diminished; it may be exposed to a temperature 60° above that of boiling water, without having its own heat increased beyond two or three degrees; or, as appears from experiments subsequently performed expressly to ascertain this point, from three to five degrees. In the former case, the body must generate a degree of heat sufficient to compensate the great quantity of caloric which is every moment abstracted from it by the intensely-cold surrounding medium. In the latter case it must generate a degree of cold sufficient to counteract the great quantity of caloric which is every moment communicated to it by the intensely-hot surrounding medium.

Powers so wonderful and so opposite appeared to the physiologists of former times to be involved in such profound mystery, that they did not even attempt to investigate their nature, or trace their mode of operation; but satisfied themselves with referring them to some innate quality of the body, and with considering them as essential attributes of life. And difficulties connected with the subject still remain, which the present state of knowledge does not permit us wholly to surmount; but we are able at least to refer these powers to their proper seat, and to trace some steps of the processes by which they produce results so wonderful and beautiful.

It is certain that, whatever be the ultimate physical processes by which the generation of heat and the production of cold are effected in the animal body, the phenomena are dependent on the condition of life. No such phenomena take place excepting in living bodies. This is illustrated in a striking manner by a series of experiments performed by Mr. Hunter. A part of the living human body was immersed in water gradually made warmer and warmer from 100° to 118°; precisely the same part of the body, dead, was immersed in the same water, and both parts, the living and the dead, were continued in this heat for some minutes. The dead part raised the thermometer to 114°; the living part raised it to no higher than 102¼°. On applying the thermometer to the sides of the living part, the quicksilver immediately fell from 118° to 104°; on applying it close to the dead part, the thermometer did not fall above a single degree; the living part actually produced a cold space of water around it. Hence in bathing in water, whether colder or warmer than the heat of the body, the water soon acquires the same temperature with that of the body; and, consequently, in a large bath the patient should move from place to place, and in a small one there should be a constant succession of water of the intended heat.

A fresh, that is, a living egg was put into cold water at about zero, frozen, and then allowed to thaw. By this process its vitality was destroyed, and consequently its power of resisting cold and heat lost. This thawed egg was next put into a cold mixture with an egg newly laid: the time required for freezing the fresh egg was seven minutes and a half longer than that required for freezing the thawed egg.

A new-laid egg was put into a cold atmosphere fluctuating between 17° and 15°; it took about half an hour to freeze; but when thawed and put into an atmosphere at 25° (10° warmer), it froze in half the time.

A fresh egg and one that had been frozen and thawed were put into a cold mixture at 15°; the thawed one soon came to 32°, and began to swell and congeal; the fresh one sunk to 29½°, and in twenty-five minutes after the dead one, it rose to 32°, and began to swell and freeze.

The result of this experiment upon the fresh egg was similar to that of analogous experiments made upon the frog, eel, snail, &c., where life allowed the heat to be diminished 2° or 3° below the freezing point, and then resisted all further decrease; but the powers of life having been expended by this exertion, the parts then froze like any other dead animal matter.

The heat of the bird is increased somewhat when it is prepared for incubation. Some eggs were taken from under a sitting hen whose temperature was 104°, at the time when the chick was about three-parts formed. A hole was broken in the shell and the bulb of a thermometer introduced; the quicksilver rose to 99½°; but in some eggs that were addled it was proved that their heat was not so high by two degrees, so that the life of the living egg assisted to support its own temperature.

These facts sufficiently show the dependence of the faculty of generating heat and of producing cold on the powers of life. But the processes by which, under the agency and control of the vital powers, these different results are effected, are various, and even opposite.

The power of generating heat is connected in the closest manner with the function of respiration, and is directly dependent upon it. The evidence of this is indubitable. For—

1. Respiration is combustion, and, like ordinary combustion, is attended with the production of heat. In ordinary combustion oxygen disappears, and a new compound is formed, consisting of oxygen combined with the combustible matter; that is, an oxidized body is generated. On burning a piece of iron wire in oxygen, the oxygen disappears, and the iron increases in weight. The oxygen combines with the iron, forming a new product, oxide of iron, and the weight of this new substance is found on examination to be exactly equal to the weight of the wire originally employed, added to the quantity of oxygen which has disappeared.

It is precisely the same in respiration. In this process oxygen combines with combustible matter, carbon: the oxygen disappears, and a new body, carbonic acid, is generated.

2. One phenomenon which invariably accompanies the combination of oxygen with combustible matter is the extrication of heat. Whenever a substance passes from a rarer into a denser state; when, for example, a gas is converted into a liquid or solid, or when a liquid solidifies, heat is evolved; because, according to the ordinary theory of combustion, the denser substance has a less capacity for caloric than the rarer, and consequently in passing from a rare into a dense state, a quantity of caloric previously combined or latent within it is set free. The combined or latent caloric contained in a body is termed its specific caloric; the caloric which is evolved on its change of state is named free or sensible caloric.

The combination of oxygen with carbon, as in the combination of oxygen with combustible matter in every other instance, must be attended with the evolution of heat. Though the product of the combustion, in the present case, be a gaseous body, carbonic acid, still, according to the ordinary theory of combustion, carbonic acid has less specific caloric, or less capacity for caloric than oxygen; and therefore in combining with carbon, a portion of its specific caloric becomes free or sensible, that is, heat is evolved. But whatever theory of combustion be adopted, the fact is certain, that whenever oxygen combines with carbon to form carbonic acid, heat is evolved; not only in the rapid union which takes place in ordinary combustion, but also in the slow combination which occurs in fermentation, putrefaction, and germination: in the latter of which processes, as in the malting of barley, the temperature rises as high as 10° above the surrounding atmosphere. The union of oxygen with carbon in the lungs during respiration must therefore necessarily produce heat, just as it does in a charcoal fire, or in any other natural process in which this combination takes place.

3. Numerous phenomena connected with the animal body show that its temperature is in strict proportion to the quantity of oxygen which is consumed in respiration, and to the quantity of carbonic acid which is formed by the union of oxygen and carbon during the process.

In all animals whose respiratory organs are so constructed, that the consumption of oxygen and the consequent generation of carbonic acid is minute in quantity, the production of heat is proportionably small. In almost the entire class of the invertebrata, the respiratory apparatus is comparatively minute and imperfect; accordingly, in these animals the power of generating heat is at the minimum. In the fish, though the respiratory apparatus be large, and though all the blood of the body circulate through it, yet only a small quantity of air is brought into contact with the respiratory organ, merely the air contained in water. In the reptile, though it possess a true and proper lung, and respire air, yet only one half of the blood of its body circulates through the comparatively small, imperfectly divided, and simply constructed air bag, which constitutes its respiratory organ. Hence, the striking contrast exhibited between the temperature of these cold-blooded creatures and that of the mammiferous quadruped, whose lung, comparatively large, and composed of innumerable minute and closely-set air vesicles, presents to the air an immense extent of surface, and the whole mass of whose blood incessantly traversing this surface, comes at every point into contact with the air.

In the various tribes of warm-blooded animals, the elevation and uniformity of the temperature are strictly proportionate to the comparative magnitude of the lungs; to the complexity of their structure; to the minuteness and number of the air vesicles; and, consequently, to the quantity of oxygen consumed, and of carbonic acid generated.

In all animals with red blood there is a strict relation between the temperature of the body and the lightness or depth of the colour of the blood; invariably the deeper the colour, the higher the temperature. Thus, the blood of the fish and of the reptile is of a light, and that of the bird of an intense red colour. It has been shown that the lightness or deepness of the colour of the blood depends on the quantity of red particles which it contains; and the chemical action between the air and the blood is carried on chiefly through the medium of the red particles.

Even in the same animal, the temperature differs at different times, according to the energy with which the process of respiration is carried on. When the circulation of the blood is sluggish and the respiration slow and feeble, the quantity of oxygen consumed is small, and the temperature low; when, on the contrary, the circulation is rapid, and the respiration energetic, the quantity of oxygen consumed is large, and the temperature proportionably high. Whatever diminishes the quantity of air that flows to the lungs, and the quantity of blood that circulates through them, diminishes the temperature. Malformation of the heart, in consequence of which a quantity of blood is sent to the system without passing through the lungs, as in the individuals termed Ceruleans—disease of the lungs, by which the access of air to the air vesicles is obstructed, as in asthma—are morbid states invariably attended with a diminution of the temperature.

When a warm-blooded animal is placed in an elevated temperature, its consumption of oxygen is comparatively small; when it is placed in a cold atmosphere, and the production of a large quantity of heat is necessary to maintain its temperature at its natural standard, its consumption of oxygen is proportionably large; accordingly, it is established by direct experiment that the same animal consumes a much larger quantity of oxygen in winter than in summer.

Due allowance being made for the difference in their bulk, young animals consume less oxygen than adults; and they have a less power of generating heat. Different species of young animals differ from each other in their power of generating heat, and the closest relation is observable between the difference in their power of consuming oxygen and that of generating heat. Puppies and kittens require so small a quantity of oxygen for supporting life, that they may be wholly deprived of this gas for twenty minutes, without material injury, while adult animals of the same species perish when deprived of it only for four minutes. As long as these young creatures retain the power of sustaining life for so protracted a period without oxygen, they are wholly incapable of maintaining their own temperature; on free exposure to air, even in summer, the heat of their body sinks rapidly, and if this exposure be continued long, they perish of cold. In like manner, young sparrows and other birds which are naked when hatched, consume little oxygen, and are incapable of maintaining their temperature; but can support life when deprived of oxygen much longer than adult birds of the same species; while young partridges which are able to retain their own temperature at the period of quitting the shell, die when deprived of oxygen as rapidly as the adult bird.

The state of hybernation illustrates in the same striking manner the relation between respiration and the generation of heat. One of the most remarkable phenomena connected with this curious state, is the reduction, sometimes even the apparent suspension, of respiration; and in all cases of hybernation, the respiratory function is performed in a feeble manner, and only at distant intervals. Exactly in proportion to the diminution of the respiration, is the reduction of the power of generating heat; so that when the state of hybernation is established, the temperature of the external parts of the body sinks nearly to that of the surrounding medium; while the internal parts, the blood, and the vital organs are only a degree or two higher. In experiments made to reduce an hybernating animal to a torpid state by cold artificially produced, De Saissy found that he could not bring on the state of hybernation by the reduction of temperature alone, without also constraining the respiration.

These and other analogous facts abundantly establish the relation between the function of respiration and that of calorification, and lead to the general conclusion that the generation of animal heat is in the direct ratio of the quantity of air and blood which are brought into contact, and which act on each other in a given time. But if the production of animal heat be really the result of combustion, if that combustion take place in the lung, and if the lung be thus the focus whence the heat radiates to every other part of the body, why is not the heat of this organ and of the parts in its immediate neighbourhood higher than the temperature of the rest of the body? Some of the internal organs are indeed a degree or two hotter than the general mass of the circulating blood, and among these the lung is admitted to rank perhaps the very highest. But how can a quantity of caloric sufficient to maintain the heat of the body in a temperature of forty degrees below zero radiate from an organ the temperature of which is only two or three degrees above that of the body itself? It is estimated that, in every minute, during the calm respiration of a healthy man of ordinary stature, 26·6 cubic inches of carbonic acid, at the temperature of 50° Fahr. are emitted, and that an equal volume of oxygen is withdrawn from the atmosphere. From these data it is calculated that, in an interval of twenty-four hours, not less than eleven ounces of carbon are consumed. Why is the lung, the seat of this combustion, not only not greatly warmer than any other organ, but why is it not even consumed by the fire which is thus incessantly burning within it.

It has been shown that when the carbon of the blood unites in the lung with the oxygen of the air, the nature of the blood, in consequence of the abstraction of carbon, undergoes an essential change, passing from venous into arterial. By an elaborate series of experiments, conducted with extraordinary care and skill, it would appear that arterial has a greater capacity for caloric than venous blood, in the proportion of 114·5 to 100. In consequence of this difference in the constitution of the two kinds of blood, the heat generated in the lung by the combustion of carbon, instead of being evolved or becoming sensible, and so raising the temperature of the organ, goes to satisfy the increased capacity for caloric of arterial blood; is spent, not in rendering the fluid sensibly warmer, but in augmenting its specific caloric. Arterial blood is not increased in temperature,* but with its absolute quantity of caloric augmented, flows from the lung to the left heart, and thence to the system. In the system, in every organ, at every point of the component tissue of every organ and at every moment of time, the blood repasses from the arterial to the venous state: by this transition its capacity for heat is diminished; the venous cannot retain in it the same quantity of caloric as the arterial blood, consequently a portion of caloric is extricated; that which was latent becomes sensible, and caloric being set free the temperature is raised. In this process the lung is not burnt, it is only rendered just sensibly warmer than any other part of the body, though it be the organ by which the whole mass of blood receives its caloric, because it is only in the capillary part of the systemic circulation, when the arterial blood again passes into the venous state, that the caloric acquired is liberated. In this manner, gently, steadily, uninterruptedly, an abundant, unceasing, and equable current of heat is distributed to every part and particle of the system.

Such is the celebrated theory of animal heat suggested by Dr. Crawford, of which it has been justly said, that it affords one of the most beautiful specimens of the application of physical and chemical reasoning to the animal economy that has ever been presented to the world.

The main position on which this theory rests—that arterial possesses a greater capacity for caloric than venous blood—professes to be founded on experiments which, though of a delicate and complex nature, are nevertheless uniform and decisive in their results. In consequence of their extreme interest and importance, these experiments have been subjected, by different physiologists, to rigid examination, with a somewhat conflicting result. The greater number of experimentalists maintain that Crawford's experiments are correct in all the essential points, and that the objections which have been urged against them do not really affect them; while others are of opinion that, even although it must, upon the whole, be admitted that the specific heat of arterial is greater than that of venous blood; yet that the excess is so small as to be inadequate to account for the effects attributed to it. Dr. Davy's experiments, which of all that have been instituted are generally conceived to be the most unfavourable to the theory of Crawford, do not afford uniform results. Three experiments out of four indicate a greater capacity in arterial than in venous blood; in those in which the experimentalist himself places the most confidence, in the relative proportion of 913 to 903; while, according to Crawford, the relative proportion is 114·5 to 100.

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* It is not a perfectly accurate statement that the temperature of venous and arterial blood is precisely the same. The latest and best experiments concur in showing that arterial blood, at least in the heart and the great arterial trunks, is one or two degrees warmer than venous blood. The weight of evidence from experiment is also in favour of the opinion, that the different parts of the body are *somewhat* less warm as they recede from the lungs and heart; but the difference is so slight that it may be disregarded in the general argument.

But when this subject is closely considered, the discrepancy in question turns out to be of no real consequence. There is a modification of the theory, which removes every difficulty, and dispenses with the necessity of any regard whatever to the point in dispute.

It has been shown that during the process of respiration more oxygen disappears than is accounted for by the carbonic acid that is generated; that this excess of oxygen is absorbed by the blood; and that in the lung the oxygen merely enters into a state of loose combination with the blood, the union being intimate and complete only in the system. The complete chemical combination of the oxygen with the carbon takes place, then, not in the lungs, but in the capillary arteries of the system; consequently it is only while flowing in capillary arteries that carbonic acid is formed; that is, it is only in these vessels that the arterial combustion takes place: of course, therefore, it is only in these vessels that heat is extricated, and only from them that it can be communicated to the adjacent parts. According to this view, wherever there is a capillary artery, the combustion of carbon incessantly goes on, and there caloric is as incessantly set free; but since there is not a point of any tissue, in which there are not capillary arteries, there is not a point from which caloric does not radiate. As soon as formed, carbonic acid passes from the capillary arteries into the capillary veins; by the veins it is transmitted to the lungs; and by the lungs it is expelled from the system. The real operations carried on in the lungs, then, are the transmission of oxygen and the extrication of carbonic acid; but this organ is not the seat of the essential and ultimate part of the function; it is merely the portal through which the elements employed in the process have their entrance and exit. Thus the question concerning the greater capacity of arterial blood for caloric is cf no importance whatever; the phenomena may be equally accounted for, whatever be, in this respect, the constitution of the blood.

The result of the whole is, the complete establishment of the fact, that the production of heat in the animal body is a chemical operation, dependent on the combination of oxygen with carbon in the capillary arteries of the system; that is, it is the result of the burning of charcoal at every point of the body.

The agent which maintains and regulates this internal fire is the nervous system. There is, indeed, reason to suppose that the nervous system, in some mode or other, contributes to the actual production of animal heat. It is established by direct experiment, that the quantity of carbonic acid formed in the system is inadequate to the supply of the caloric expended by it; that in a given time more heat is abstracted from the body by the surrounding medium, than can be accounted for by the consumption of the amount of carbonic acid thrown off by the lungs during the same interval. There is evidence that the source of this additional heat is the nervous system.

The influence exerted by the nervous system over the production of animal heat, is demonstrated by the fact, established by numerous observations and experiments, that whatever weakens the nervous power, proportionally diminishes the capacity of producing heat. For,

1. The destruction of a portion of the spinal cord diminishes the temperature of an animal without, as far as is ascertained, the disturbance of any other function.

2. The privation of the heart and blood-vessels of the nervous influence, as by decapitation, though the passage of the blood through the lungs and its ordinary change from the venous to the arterial state be maintained by artificial respiration, greatly diminishes, if it do not altogether suspend, the generation of animal heat.

3. The abolition of sensibility by the administration of a narcotic poison, artificial respiration being maintained, as effectually disturbs the generation of animal heat as decapitation; while the power of generating heat is restored, in the exact proportion to the return of the sensibility by the cessation of the action of the poison.

4. The temperature of an organ is found, by direct experiment, to be diminished by the division of the nerves that supply it with nervous influence. The nerves that supply the horn were divided on one side of the body in a young deer; the other horn was left entire. The temperature of the horn—the nerves of which had been divided—was found, after some hours, to be considerably diminished, and it continued diminished for several days: at length its temperature was restored. On examining the horn about ten days after the operation had been performed, the divided nerves were found to be connected by a newly-formed substance; thus apparently accounting for the loss of temperature in the first instance, and for its subsequent restoration.

But although these and other analogous facts prove, beyond all question, the important influence of the nervous system over the development of animal heat, yet the mode in which that influence operates is not ascertained. Its action may be either direct or indirect. The nerves may possess some specific power of generating heat,—extricating it immediately from the blood by a process analogous to secretion,—or they may evolve it indirectly by other operations, as by some of the processes of nutrition. Each hypothesis is maintained by able physiologists; but the balance of evidence (as will appear hereafter) is greatly in favour of the opinion that the influence of the nervous system over this process is altogether indirect. A beautiful illustration of this is afforded in the following operation, which is going on, without ceasing, every instant during life.

The skin which forms the external covering of the body is composed essentially of gelatin. No gelatin is contained in the blood; but the albumen of the blood is capable of being converted into gelatin by the addition of oxygen. Albumen is received by the capillary artery of the skin; the blood, of which albumen forms so important a constituent, contains a quantity of oxygen which it receives at the moment of inspiration, and which it retains in a state of loose combination. Under the influence probably of the organic nerve, the capillary artery chemically combines a portion of the free oxygen with the albumen of the blood, and gelatin is the result. In this process the albumen gives off carbon; the blood affords oxygen; the two elements unite; carbonic acid is formed; and, as in every other instance in which carbonic acid is formed, heat is evolved. In this manner a fire is kindled, and is kept constantly burning, where it is most needed to counteract the influence of external cold, at the external surface of the body.

Such are the main points which have been established in relation to the production and distribution of animal heat. But it has been shown that the living body is capable of bearing without injury a temperature by which it is rapidly consumed when deprived of life. By what means does the vital power enable the body to resist the influence of such intense degrees of heat?

Two circumstances are observable when the body is placed in a temperature greatly higher than its own. First, it can endure such a temperature only in the medium of air. Air can easily be borne at the temperature of 260°: aqueous vapour at the temperature of 130° few Europeans are capable of enduring longer than twelve minutes; the peasants of Finland appear to be able to sustain it, for the space of half an hour, as high as 167°: but the hottest liquid water-bath which any one seems to have been able to bear for the space of ten minutes, is the hottest spring at Barêges, the temperature of which is 113°. But in heated air, the quantity of heat in actual contact with the body is much less than in the other media; because in proportion as the air is heated it is expanded, and in proportion as it is expanded the particles are diminished that come into contact with the body.

In the second place, the afflux of the colder fluids from the central parts of the system to the surface may for a time exert some influence in keeping down the temperature of the body. But above all this, in the third place, a twofold provision is made in the body itself for the reduction of its temperature when exposed to intense degrees of heat: by the one, the power with which it is endowed of producing heat is diminished; by the other, cold is positively generated.

It has been shown that in proportion to the elevation of the temperature to which the body is exposed the blood becomes less venalized, and in the proportion in which the blood retains its arterial character the consumption of oxygen is diminished. Venous blood contains an excess of carbon; arterial blood an excess of oxygen. Consequently, in proportion as the blood retains its arterial character it affords less carbon for the combination of oxygen—that is less inflammable matter. At an elevated temperature therefore there must, of necessity, be a diminished production of heat within the body, since the blood contains a diminished quantity of combustible material.

Moreover, in proportion to the elevation of the temperature to which the body is exposed, evaporation takes place from the entire surface of the pulmonary vesicles. No experiments have been performed which enable the physiologists to ascertain precisely the quantity of vapour exhaled from the lungs in a given time, when the body is exposed to a given degree of heat; but both observation and experiment show that it is very great. The blood pours out upon the whole surface of the air-vesicles a quantity of moisture in the form of water: by the surrounding air this water is converted into vapour: by the conversion of a fluid from the state of a liquid into that of vapour caloric is absorbed: by the absorption of caloric cold is generated, and that to such a degree that fluids exposed to the influence of evaporation may be frozen in the intensest heat of summer. The very process by which art, aided by science, affords to the inhabitants of warm climates the luxury of ice, is that by which nature generates cold in the human lungs when the body is exposed to a temperature above its own. Not only, then, is the lung the instrument by which the body acquires the power of evolving heat in greater or less quantity in proportion to the demands of the system, but this very same organ, under a change of circumstances, produces the directly contrary effect, and actually generates cold.

In the process of producing cold, the skin is a powerful auxiliary to the lungs. More fluid is, indeed, evaporated from the surface of the skin in the form of perspiration, than from the lungs in the form of vapour; the cutaneous, like the pulmonary evaporation, increases in the ratio of the temperature, and both co-operate in abstracting the excess of caloric.

Finally, in proportion to the elevation of the temperature is the acceleration of the circulation: the pulse is augmented in power, and doubled or trebled in frequency; but in proportion to the rapidity of the circulation is the increase of the quantity of evaporable matter which is transmitted to the evaporating surfaces.

From the whole it appears that by the combination of carbon and oxygen provision is made for the production of the greatest quantity of caloric that can at any time be required for the wants of the system; that when a decreased evolution of heat is necessary a smaller quantity of carbon and oxygen is brought into union; and that when, from exposure to intense degrees of heat, it is requisite for the maintenance of the temperature of the body at its own standard, that it should actually generate cold, it accomplishes this object by the evaporation of water.

CHAPTER XIV.

OF THE FUNCTION OF DIGESTION.

Process of Assimilation in the plant; in the animal—Digestive apparatus in the lower classes of animals; in the higher classes; in man—Digestive processes—Prehension, Mastication, Insalivation, Deglutition, Chymification, Chylification, Absorption, Fecation—Structure and action of the organs by which these operations are performed—Ultimate results—Powers by which those results are accomplished—Two kinds of digestion, a lower and a higher; the former preparatory to the latter.

Digestion is the function by which the aliment is converted into nutriment. No food can nourish until it be converted into a fluid analogous in chemical composition to that of the body by which it is assimilated. The conversion of the crude aliment into such a fluid is effected by a vital power peculiar to living beings, by which they subvert the constitution of other organised bodies, and cause them to assume their own. They accomplish this change by the agency of certain secretions which they elaborate in their own organs, and which they add to the substances they receive as aliment. By the action of these secretions, the chemical composition of the aliment is brought into a close affinity to that of the body which it nourishes.

Fixed immoveably to the soil by its roots, the nutritive apparatus of the plant is always in contact with its food, which is slowly but unceasingly absorbed according to the wants of its system. But the animal endowed with the faculty of locomotion receives its aliment into the interior of its body, that it may transport its food along with it in all its changes of place; and that, as in the plant, its food may be always in contact with its nutritive apparatus. The interior nutrition of the animal and the convergence of its nutritive apparatus to the centre of its system, and the exterior nutrition of the plant and the divergence of its nutritive apparatus to the peripheral extremity of its body, are differences in their mode of nutrition, connected with essential differences in the mode of life peculiar to the two beings.

Plant-like animals have a plant-like mode of nutrition. The transition from the one class to the other is so gradual as to be almost insensible. Fixed to the same spot in the ocean as the tree to the land, the nutritive surface of the poriferous animal is always in contact with the water, as the soil is with the external surface of the plant. The cellular substance of which the bag of the poriferous animal is composed is permeated in all directions by ramifying and anastomosing canals, which, beginning by minute pores placed on the external surface, terminate in larger orifices, termed vents, which are fecal openings. These internal canals are incessantly traversed by streams of water, which enter through the minute, and are discharged through the larger, orifices. By these currents the nutrient matter contained in the water is conveyed to every part of the body, and the streams that issue from the fecal orifices abound with minute flocculent particles, the residue of the digested matter. No separate part of the body is appropriated to the function of digestion any more than in the plant; there is merely a general absorbent surface; the water is to this animal what the soil is to the plant; its whole surface is a root; every point of that surface is constantly in contact with its food, and every point is absorbent.

Comparative anatomy, which has succeeded in tracing through the different classes, orders, genera, and countless tribes of animals, the modifications in form and structure of the digestive apparatus, has shown that those modifications are invariably in strict adaptation to the kind of food on which the apparatus is destined to act, and to the extent of the elaboration requisite to convert crude aliment into proper animal substance. To trace this adaptation through the rising and ever-varying series, is a most interesting and instructive study —not only exhibiting, in the very organs that elaborate its food, the physical and even the mental qualities assigned by the hand of nature to each individual, but oftentimes shedding a clear and bright light on the complex structures of the highest and most perfect organisation. Striking and beautiful illustrations are afforded by these investigations of the principle formerly insisted on (Chapter I.), that the communication of the higher faculties exalts the apparatus even of the very lowest processes, that the latter may work in harmony with the former. In conformity with this principle, as the nobler endowments exalt the animal in the scale of organisation, so even its very digestive apparatus becomes extended, isolated, complex and refined.

The highest and most perfect form of the digestive apparatus is that which is disposed in a series of chambers in free communication with each other. In these chambers the food undergoes a succession of changes, by which it is progressively assimilated to the nature of animal substance. This assimilation, however, is never effected by the sole agency of the chambers themselves; it is accomplished, to a great extent, by the influence of special organs placed in the neighbourhood of the digestive chambers. In the lowest animal there is but one substance and one surface for every function; in the highest, even for the performance of the lowest function, there is the combination of many substances which are arranged in complex modes.

In man, the digestive chambers are five; the auxiliary organs are many.

The first of these chambers is the cavity called the mouth; the second is the bag termed the pharynx; the pharynx communicates by the œsophagus with the third chamber, the stomach; the fourth chamber consists of the convoluted tubes named the small intestines, and the fifth consists of the larger tubes, denominated the large intestines. The assistant organs are, first, numerous appendages to the mouth, namely, the tongue, the teeth, the salivary glands, and the muscles that work the jaws; and, secondly, certain appendages to the small intestines, namely, the pancreas, the liver, the mesenteric glands, and the lacteal vessels.

By the mouth the food is softened and reduced to a pulp; by the tongue, materially aided by the soft palate, this pulp, when duly prepared, is transmitted to the pharynx; received by the pharynx, it is sent on to the œsophagus; by the œsophagus, it is conveyed to the stomach; in the stomach, it is converted into a peculiar substance called chyme; the chyme, passing from the stomach into the first portion of the small intestines, is there converted into the substance called chyle; the chyle, carried slowly along the remaining portion of the small intestines, is successively absorbed by the lacteals; by the lacteals, it is conveyed through the mesenteric glands to the thoracic duct, and by the thoracic duct it is poured into the venous blood close to the heart. By the large intestines the refuse matter is conveyed out of the system.

The function of digestion consists, then, of the following processes:—

1. Prehension. 2. Mastication. 3. Insalivation. 4. Deglutition. 5. Chymification. 6. Chylification. 7. Absorption. 8. Fecation.

Prehension is the reception of the aliment; mastication is the mechanical comminution of it; insalivation is the admixture of it with certain juices poured into the mouth; deglutition is the transmission of it, when duly moistened and divided, into the stomach; chymification is the conversion of it into chyme; chylification is the conversion of the chyme into chyle; absorption is the assumption of the chyle by the lacteals and the transmission of it into the blood, and fecation is the separation and discharge of the refuse matter. Each part of this extended apparatus is modified in structure so as specially to fit it for the performance of the office which is appropriated to it.

The mouth is not merely the opening between the two lips, but consists of an oval chamber, bounded above by the upper jaw and the palate; below by the tongue and the lower jaw; laterally by the cheeks; behind by the soft palate; and before by the lips.

The upper and lower jaw, the palate bones, and the teeth, constitute the hard or the bony parts of the mouth. The soft parts consist of the lips, the cheeks, the soft palate, the tongue, and the mucous membrane which lines the whole.

The lips and cheeks are composed principally of muscles, covered on the outside by the skin, and lined on the inside by the mucous membrane of the mouth. In the interspaces between the muscles is disposed a quantity of fat, which gives form to the face, facilitates the movements of the muscles, and protects the glands, blood-vessels, and nerves, with which all these organs are most abundantly supplied.

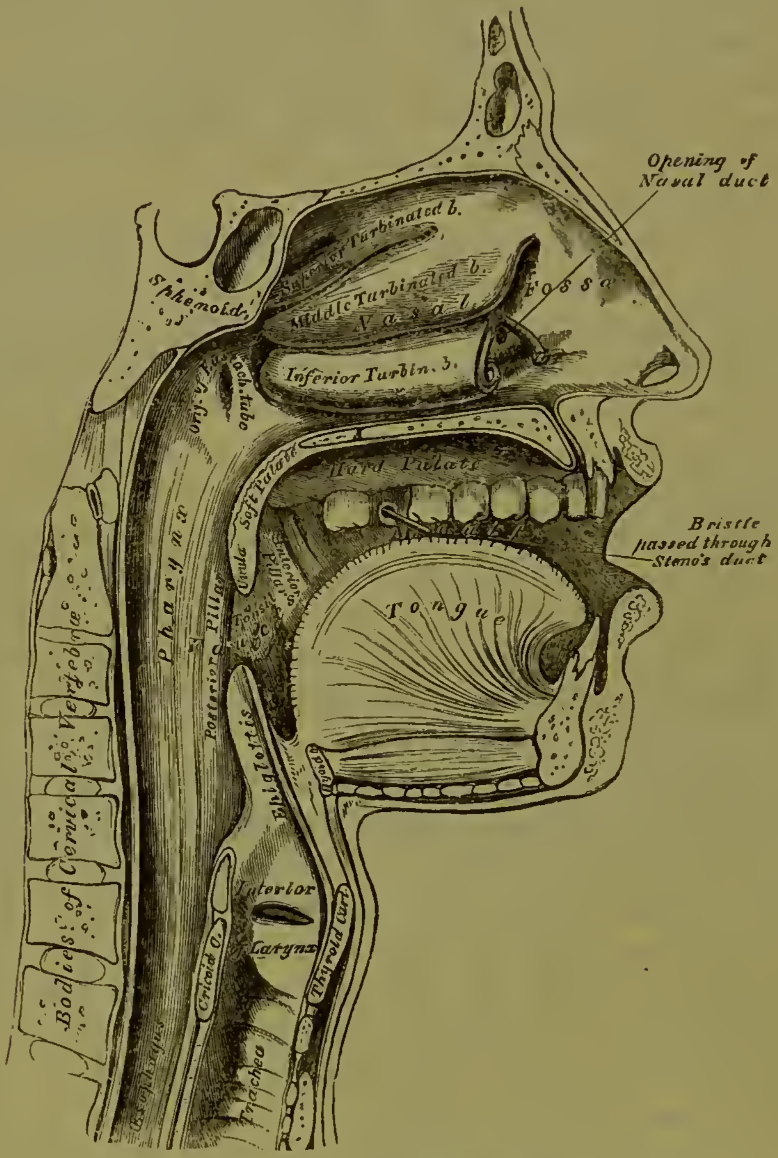
The roof of the mouth, called the palate (Fig. 81), consists partly of bony and partly of membranous substance. The bony part of the palate forms an arch in the upper jaw, the position of which in the erect posture is horizontal: the membranous part of the palate consists of the mucous membrane of the mouth, which affords a covering to the bony part of the palate.

From the posterior part of the bony arch of the palate is suspended, transversely, a moveable partition, called the soft palate (Fig. 81), which is composed of muscular fibres enclosed in the mucous membranes of the mouth. No less than ten distinct muscles enter into the composition of the soft palate. These muscles are disposed in such a manner that they render the organ capable of descending and of applying itself against the tongue (Fig. 81), so as completely to close the passage between the mouth and the pharynx (Fig. 81), and of ascending and carrying itself obliquely backwards towards the posterior wall of the pharynx, so as completely to close the passage between the pharynx and the nose (Fig. 81, nasal fossæ); hence this moveable partition performs the office of a double valve, closing the passage from the mouth to the pharynx, and from the pharynx to the nose.

From the centre of the soft palate hangs pendulous the conical-shaped body called the uvula (Fig. 81), which consists of a small muscle enveloped in the mucous membrane of the mouth. The uvula assists in completing the valve formed by the soft palate; it is also an important organ in the modulation of the voice. When destroyed by disease, both the deglutition of the food and the sound of the voice become imperfect.

The lateral edges of the soft palate separate into two layers, which enclose between them the bodies called the tonsils (Fig. 81), two glands commonly about the size of an almond. These organs co-operate with other glands in secreting the fluids of the mouth.

Fig. 81.



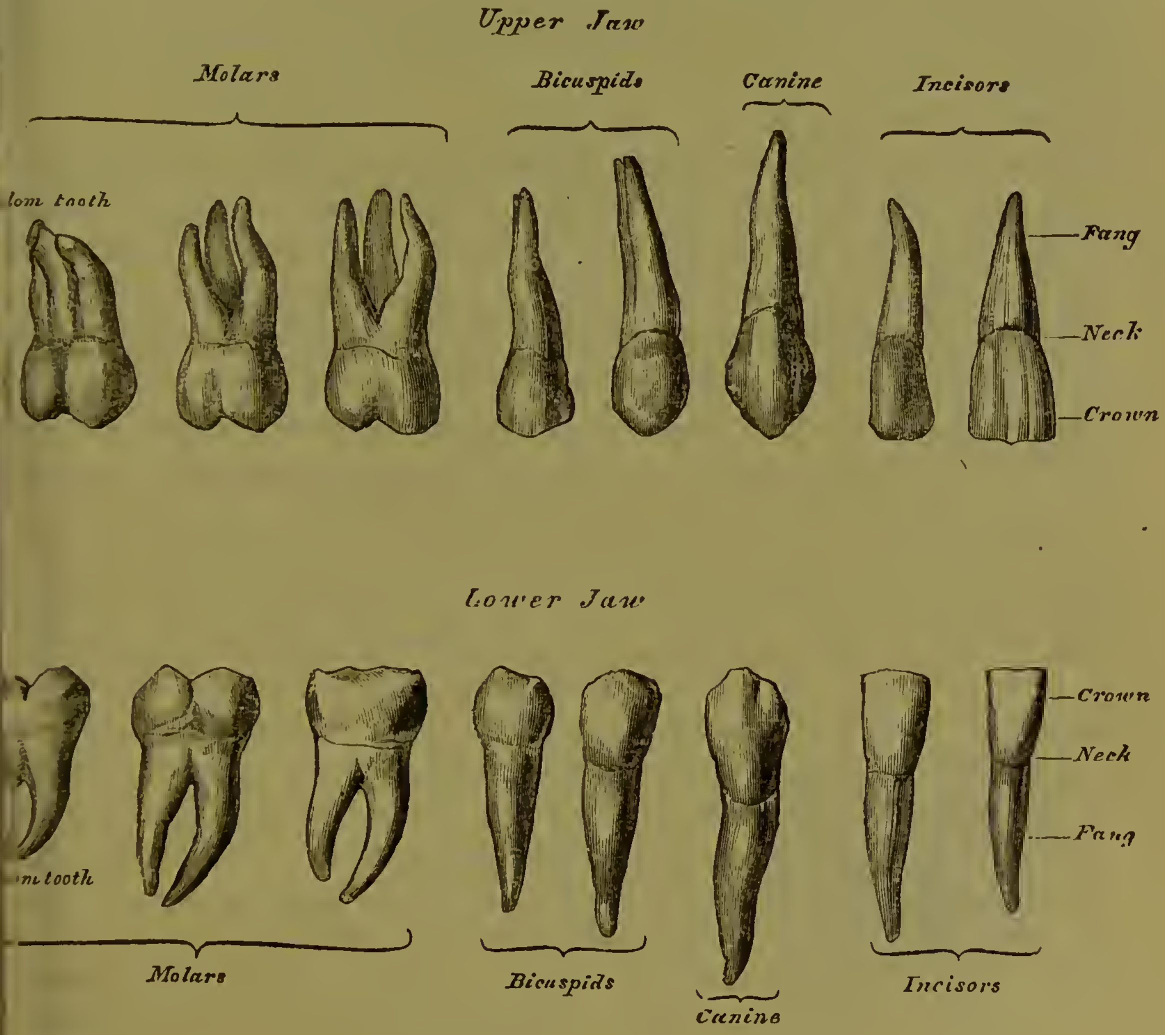
Sectional view of the Nose, Mouth, Pharynx, etc.

The tongue (Fig. 81) is composed of six distinct muscles enveloped in the mucous membrane of the mouth. The fibres of these muscles are so interwoven with each other as to form an intricate net-work; and their number, arrangement, and exquisite organisation render the organ capable of executing a surprising variety of movements with the most perfect precision, and with a velocity of which the mind can scarcely form a conception: some of these movements being requisite to bring the aliment under the operation of mastication, and others to produce articulate speech.

The tongue divided into base, apex, and dorsum, is supported by a bone called the hyoid bone (os hyoides), (Fig. 81), which, unlike any other bone of the body, is placed at a distance from the general skeleton, and completely imbedded in muscles. This singularly posted and delicately constructed bone is not only connected with the tongue, but with many other highly important muscles, to which it affords a support and a lever.

Each jaw is provided with sixteen teeth (Fig. 82), arranged with perfect uniformity, eight on each side of each jaw; those of the one side exactly corresponding with those of the other. The teeth, from

Fig. 82.



The Permanent Teeth. External view.

he differences they present in their size, form, mode of connection with he jaw, and use, are divided into four classes, namely, on each side of ach jaw, two incisors; one canine; two bicuspid; and three molar. (See Fig. 82.)

The incisor, or cutting teeth, are situated in the front of the jaw; that directly in the centre is called the central; and the next to it the lateral incisor. Their office, as their name imports, is to cut the food, which they do, on the principle of shears or scissors.

Standing next to the lateral incisor is the canine, or eye-tooth. It is the longest of all the teeth. Its office is to tear such parts of the food as are too hard to be readily divided by the incisors.

Next the cuspid are the bicuspid, two on each side (Fig. 82), so named from their being provided with two distinct prominences or points. Their office is to tear tough substances preparatory to their trituration by the next set.

The molars, or the grinders, three on each side, are provided with four or five prominences on the grinding surface, with corresponding depressions, which are so arranged that the elevations of those of the upper are adapted to the concavities of those of the lower jaw, and the contrary.

From the incisor to the molar teeth there is a regular gradation in size, form, and use, the cuspid holding a middle place between the incisor and the bicuspid, and the bicuspid being in every respect intermediate between the cuspid and the molar. Thus the incisor are adapted only for cutting, the cuspid for tearing, the bicuspid partly for tearing and partly for grinding, and the molar solely for grinding. The incisor has only a single root, which is nearly round, and quite simple (Fig. 82); the cuspid has only a single root, but this is flattened and partially grooved; even the bicuspid has only a single root, but this is commonly divided at its extremity, and is always so much grooved as to have the appearance of two fangs partially united, the body having two points instead of one, thus approaching it to the form of the molar; and these last have always two, sometimes three, occasionally four roots, and their body is greatly increased in size, and has a complete grinding surface.

In some animals whose food and habits require the utmost extension of the office of a particular class of teeth, a corresponding development of that class takes place. Thus in the carnivora, as is strikingly seen in the tiger and the polar bear, the cuspid or canine teeth are prodigiously elongated and strengthened, in order to enable them to seize their food, and to tear it in pieces. On the other hand, in the rodentia, or gnawing animals, as in the beaver, the incisors are exceedingly elongated; while in the graminivora, and especially in the ruminantia, the molar teeth are by far the most developed. In each case the other kinds of teeth are of little comparative importance; sometimes they are even altogether wanting.

So intimately are these organs connected with the kind of food by which life is sustained, and the kind of food with the general habits of the animal, that an anatomist can tell the structure of the digestive organs, the kind of nervous system, the physical and even the mental endowments; that is, the exact point in the scale of organisation to which the animal belongs, merely by the inspection of the teeth.

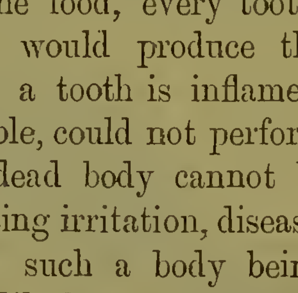
In man, the several classes of the teeth are so similarly developed, so perfectly equalized, and so identically constructed, that they may be considered as the true type from which all the other forms are deviations.

For the accomplishment of their office, the teeth must be endowed with prodigious strength: for the fulfilment of purposes immediately connected with the apparatus of digestion, it is necessary that they should be placed in the neighbourhood of exceedingly soft, delicate, irritable, and sentient organs. That they may possess the requisite degree of strength, they are constructed chiefly of a kind of bone, the hardest organised substance. (Chapter VI.)

Had a highly-organised and sensitive body been made the instrument of cutting, tearing, and breaking down the food, every tooth, every time it comes in contact with the food, would produce the exquisite pain now occasionally experienced when a tooth is inflamed. Yet a body wholly inorganic and therefore insensible, could not perform the office of the instrument: first, because a dead body cannot be placed in contact with living parts without producing irritation, disease, and consequently pain; and, secondly, because such a body being incapable of any process of nutrition, must speedily be worn away by friction, and there could be no possibility of repairing or of replacing it. The instrument in question, then, must possess hardness, durability, and, to a certain extent, insensibility; yet it must be capable of forming an intimate union with sentient and vital organs, must be apable of becoming a constituent part of the living system.

To communicate to it the requisite degree of hardness, the hard substance forming its basis is rendered much harder than common bone.

Fig. 83.



Magnified section of a tooth, to illustrate the arrangement of the fibrous crystals composing the enamel. 1, cavity of the tooth; 2, bony substance; 3, enamel showing the crystals disposed in radii.

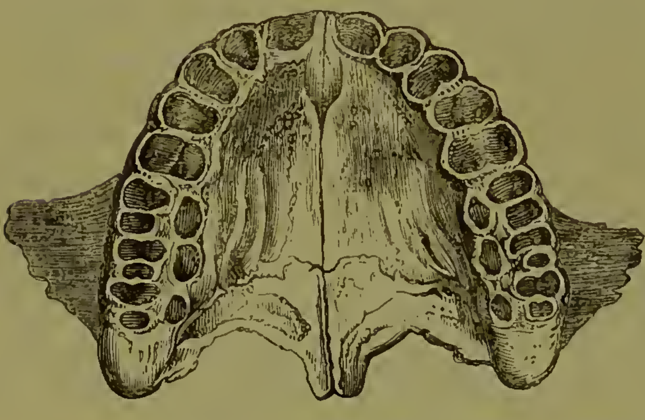
When a vertical section is made in the ooth, it is found to contain a cavity of considerable size, termed the dental cavity, which, large in the body of the tooth, gradually diminishes through the whole length of the root. The dental cavity is ined throughout with a thin, delicate, and ascular membrane, continued from that which lines the jaw. It contains a pulpy ubstance. This pulp, highly vascular and xquisitely sensible, is composed almost entirely of blood-vessels and nerves, and is the source whence the bony part of the tooth derives its vitality, sensibility, and nutriment. The blood-vessels and nerves that compose the pulp enter the dental cavity through a minute hole at the extremity of the root. The membrane which lines the dental cavity is likewise continued over the external surface of the root, so as to afford it a complete envelope.

In this manner an instrument is constructed possessing the requisite hardness, durability, and insensibility; yet organized, alive, as truly an integrant portion of the living system as the eye or the heart.

No less care is indicated in fixing than in constructing the instrument. It is held in its situation not by one expedient, but by many.

1. All along the margin of both jaws is placed a bony arch, pierced with holes, which constitute the sockets, called alveoli, for the teeth (Fig. 84). Each socket or alveolus is distinct, there being one alveolus for each fang. The adaptation of the root to the alveolus is so exact, and the adhesion so close, that each root is fixed in its alveolus just as a nail is fixed when driven into a board.

Fig. 84.



Upper jaw, showing the alveoli.

2. The roots of the tooth, when there are more than one, deviate from a straight line; and this deviation from parallelism, on an obvious mechanical principle, adds to the firmness of the connexion.

3. Adherent by one edge to the bony arch of the jaw, and by the other to the neck of the tooth, is a peculiar substance, dense, firm, membranous, called the gum, less hard than cartilage, but much harder than skin, or common membrane; abounding with blood-vessels, yet but little sensible; constructed for the express purpose of assisting to fix the teeth in their situation.

4. The dense and firm membrane covering the bony arch of the jaw is continued into each alveolus which it lines: from the bottom of the alveolus this membrane is reflected over the root of the tooth, which it completely invests as far as the neck, where it terminates, and where the enamel begins: this membrane, like a tense and strong band, powerfully assists in fixing the tooth.

5. Lastly, the vessels and nerves which enter at the extremity of the root, like so many strings, assist in tying it down; hence, when in the progress of age all the other fastenings are removed, these strings hold the teeth so firmly to the bottom of the socket, that their removal always requires considerable force.

But a dense substance like enamel, acting with force against so hard a substance as bone, would produce a jar which, propagated along the bones of the face and skull to the brain, would severely injure that tender organ, and effectually interfere with the comfort of eating.

This evil is guarded against,

1. By the structure of the alveoli, which are composed not of dense and compact, but of loose and spongy bone. This cancellated arrangement of the osseous fibres is admirably adapted for absorbing vibrations and preventing their propagation. (Chapter VI.)
2. By the membrane which lines the socket.
3. By the membrane which covers the root of the tooth; and,
4. By the gum.

These membranous substances, even more than the cancellated structure of the alveoli, absorb vibrations and counteract the communication of a shock to the bones of the face and head when the teeth act forcibly on hard materials; so many and such nice adjustments go to secure enjoyment, nay to prevent exquisite pain, in the simple operation of bringing the teeth into contact in the act of eating.

The teeth in mastication are passive instruments put in motion with the jaws. The upper jaw is fixed, the lower only is moveable. The lower jaw is capable of different motions; depression, elevation, a motion forwards and backwards, and a lateral motion. These simple motions are capable, by combination, of producing compound motions. Numerous muscles, some of them endowed with prodigious power, are so disposed and combined as to be able, at the command of volition, to produce any of these motions that may be required, simple or compound.

By the combination, succession, alternation, and repetition of these motions, the lower is made to produce upon the upper jaw all the variety of pressure necessary for the mastication of the food. In this process the muscles of the tongue perform scarcely a less important part than the muscles of the lower jaw. Some of its muscular fibres horten the tongue, some give it breadth, others render it concave, and thers convex: so ample is the provision for moving this organ to ifferent parts of the mouth and fauces, whether to bruise the softer parts of the aliment against the palate, to mix it with the saliva, or to place it under the pressure of the teeth.

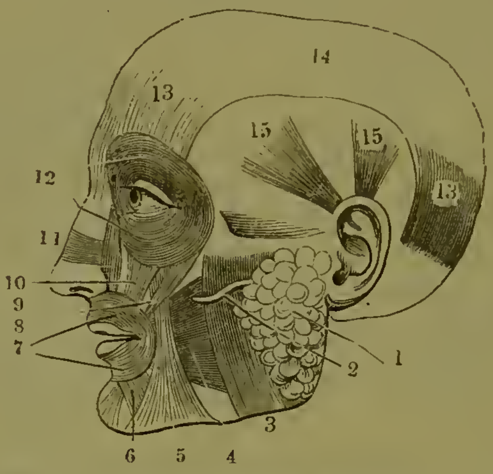
By the combined action of the muscles of the lower jaw and tongue, nd that of the teeth, the food is bruised, cut, torn, and divided into minute fragments. This operation is of so much importance that the whole process of digestion is imperfect without it. It is proved by irect experiment that the stomach acts upon the aliment with a acility in some degree proportionate to the perfection with which it is masticated. If an animal swallow morsels of food of different bulks, nd the stomach be examined after a given time, digestion is found to be the most advanced in the smallest pieces, which are often completely softened, while the larger are scarcely acted upon at all.

At the same time that, by the operation of mastication, the aliment undergoes mechanical division, it imbibes a quantity of fluid derived from various sources.

1. From the membrane which lines the internal surface of the mouth, and which affords a covering to all the parts contained in it.

2. From numerous minute glands placed in clusters about the cheeks, gums, lips, palate, and tongue. Each of these glands is furnished with its own little duct, which, piercing the mucous membrane, opens into the cavity of the mouth. From these glands is derived the fluid with which the interior of the mouth is lubricated. It consists of a glutinous, adhesive, transparent fluid, of a light-grey tint, salt taste, and slightly alkaline nature, termed mucus.

Fig. 85.



View of the parotid gland, with the muscles of the face. 1, parotid gland; 2, parotid duct; 3, masseter muscle; 4, buccinator; 5, triangularis, or depressor of the angle of the mouth; 6, depressor of the lower lip; 7, orbicularis, or circular muscle of the mouth; 8, great zygomatic, or the distorter of the mouth, as in laughing; 9, elevator of the angle of the mouth; 10, elevator of the upper lip, and wing of the nose; 11, compressor of the cartilage of the nose; 12, orbicularis, or circular muscle of the eyelids; 13, occipito-frontalis; elevator of the eyelids; motor of the scalp, &c., an important muscle of expression; 14, tendinous portion of the occipito-frontalis; 15, elevator of the ear.

3. From six large glands placed symmetrically, three on each side, termed the salivary glands, namely, the parotid (Fig. 85, 1), situated before the ear; the submaxillary, situated beneath the lower jaw; and the sublingual, situated immediately under the tongue. Each of these glands is provided with a duct (Fig. 85, 2), by which it pours the fluid it elaborates, called saliva, into the mouth.

The other fluids of the mouth are always mixed with the saliva, and are all commonly included under that name. The secretion of these fluids is unceasing, and they pass into the stomach by successive acts of deglutition at nearly regular intervals; so that the stomach, after it has been some time without food, contains a considerable quantity of these fluids. But they are chiefly needed during the operation of mastication, and two provisions are made for securing their flow in the greatest abundance at that time.

First, the situation of the glands is such that they are all exposed to the action of the muscles of mastication, by which action the glands are excited, a large quantity of blood is determined to them, and the quantity of fluid they secrete is proportionate to the quantity of blood they receive. Secondly, the glands are placed under the influence of the mind, so that the very thought, and still more the taste, of grateful food, acting upon them as an additional stimulus, causes an additional secretion. The quantity of fluid formed from these different sources, and mixed with the food during the mastication of an ordinary meal, is estimated at half a pint. It must commonly be more than this, because, in a case described by Dr. Gairdner, of Edinburgh, in which the œsophagus had been cut through, it was observed that from six to eight ounces of saliva were discharged during a meal, which consisted merely of broth injected through the divided œsophagus into the stomach.

Saliva is a frothy, watery fluid, in its healthy state nearly insipid, and of a slightly alkaline nature. It is composed of water, a peculiar animal substance called ptyalin, mucus, and several salts. It produces important changes on the food. By the water, and the salts contained in it, it softens and dissolves the food; and thus, while it renders it easier to be swallowed, it prepares it for the subsequent changes it is to undergo. To this latter object, the assimilation of the food, it seems to communicate the first tendency by the azotised substances, the salivary, and the albuminous matter which it adds to it. From this, the commencement of the assimilative process to its completion, animalised substances are successively added to the food which have he property of converting the food more and more into the nature of animal substance.

Comminuted by the teeth, and softened by the saliva, the food is educed to a pulp. In this pulp there is a complete admixture of all he alimentary substances with the assimilative matter secreted from he blood, into the nature of which it is to be ultimately changed. The mass is at the same time brought to the temperature of the blood.

As long as the operations of mastication and insalivation go on, the mouth forms a closed cavity from which the food cannot escape; for he lips enclose it before, the cheeks at the sides, the tongue below, nd the soft palate behind, the inferior edge of which being applied in lose and firm contact with the base of the tongue, prevents all comunication between the mouth and the pharynx.

When, by mastication, the food is sufficiently divided, and by insaliation softened and animalised to fit it for the future changes it is to undergo, it is collected by the tongue, and carried by that organ to the back part of the mouth. The soft palate (Fig. 81), obedient to the stimulus of the duly-prepared food, rises the instant it is touched by it, and affords it a free passage to the pharynx (Fig 81).

In front are the two entrances from the nose with the mouth below them, on either side are the Eustachian tubes (Fig. 81), which open on a level between the nose and mouth above the soft palate, and below are the passages to the lungs and stomach called trachea and œsophagus (Fig. 81), the latter always open, and the former guarded by the valve-like epiglottis (Fig. 81), and by its active closing lips called glottis.

Were the food to enter the Eustachian tubes or the nose, it would occasion great inconvenience; were it to enter the glottis, it would cause death. It is prevented from entering the Eustachian tubes and the nose by the soft palate (Fig. 81), which by the very act of rising to afford an opening from the mouth to the pharynx, is carried over the other apertures so as completely to close them. By the varied direction of the muscular fibres which enter into the composition of this organ, it is enabled to execute the different and even opposite motions required in the performance of its important office.

The food is prevented from entering the glottis partly by a cartilaginous valve (Fig. 81), termed the epiglottis, placed immediately above the glottis, and attached to the root of the tongue (Fig 81). In delivering the food to the pharynx the tongue passes backwards. In passing backwards it pushes in the same direction the epiglottis which is attached to it, and so necessarily carries it over the glottis, closing the aperture.

It is deeply interesting to observe the part performed in these operations by sensation and volition, and the boundary at which their influence terminates and consciousness itself is lost. Mastication, a voluntary operation, carried on by voluntary muscles, at the command of the will, is attended with consciousness, always in the state of health of a pleasurable nature. To communicate this consciousness, the tongue, the palate, the lips, the cheeks, the soft palate, and even the pharynx, are supplied with a prodigious number of sentient nerves. The tongue especially, one of the most active agents in the operation, is supplied with no less than six nerves derived from three different sources. These nerves, spread out upon this organ, give to its upper surface a complete covering, and some of them terminate in sentient extremities visible to the naked eye. These sentient extremities, with which every point of the upper surface, but more especially the apex, is studded, constitute the bodies termed papillæ, the immediate and special seat of the sense of taste. This sense is also diffused, though in a less exquisite degree, over the whole internal surface of the mouth.

Close to the sense of taste is placed the seat of the kindred sense of smell. The business of both these senses is with the qualities of the food. Mastication at once brings out the qualities of the food, and puts the food in contact with the organs that are to take cognizance of it. Mastication, a rough operation, capable of being accomplished only by powerful instruments which act with force, is carried on in the very same spot with sensation, an exquisitely delicate operation, having its seat in soft and tender structures, with which the appropriate objects are brought into contact only with the gentlest impulse. The agents of the coarse and the delicate, the forcible and the gentle operations are in close contact, yet they work together not only without obstruction, but with the most perfect subserviency and co-operation.

The movements of mastication are produced, and, until they have accomplished the objects of the operation, are repeated by successive acts of volition. To induce these acts, grateful sensations are excited by the contact of the food with the sentient nerves so liberally distributed over almost the whole of the apparatus. To the provision thus made for the production of pleasurable sensation, is superadded the necessity of direct and constant attention to the pleasure included in the gratification of the taste. It is justly observed by Dr. A. Combe, that without some degree of attention to the process of eating, and some distinct perception of its gratefulness, the food cannot be duly digested. When the mind is so absorbed as to be wholly unconscious of it, or even indifferent to it, the food is swallowed without mastication: then it lies in the stomach for hours together without being acted upon by the gastric juice, and if this be done often, the stomach becomes so much disordered as to lose its power of digestion, and death is the inevitable result: so that not only is pleasurable sensation annexed to the reception of food, but the direct and continuous consciousness of that pleasurable sensation during the act of eating is made one of the conditions of the due performance of the digestive function.

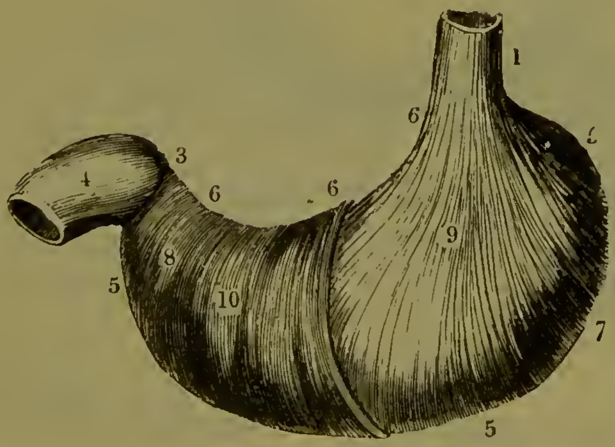
With the operation of mastication and one part of the process of deglutition, immediately to be noticed, the agency of volition and sensation cease. Beyond this the function of digestion is wholly an organic process. In addition to the reasons assigned why all the organic processes are placed alike beyond the cognizance of sense and the control of the will, there is this special reason why, in the function of digesion, they cease at the exact boundary assigned them.

Every time the act of deglutition is performed, the openings to the windpipe and to the nose are closed, so that during this operation all ccess of air to the lungs is stopped; consequently it is necessary that he passage of the food through the pharynx should be rapid. Mastiation, a voluntary process, may be performed slowly or rapidly, perfectly or imperfectly, without serious mischief; but life depends on the passage of the food through the pharynx with extreme rapidity and with the nicest precision. It is therefore taken out of the province of volition and intrusted to organs which belong to the organic life, organs which carry on their operations with the steadiness, constancy, and exactness of bodies whose motions are determined by a physical law.

No sooner does the duly-prepared food touch the soft palate, than the whole apparatus of deglutition is instantly in motion. This moveable partition suddenly rises to afford to the food a free passage to the pharynx. The pharynx itself, at the same instant, rises to receive the morsel thrust towards it by the pressure of the tongue; and one muscle, the stylo-pharyngeus, which concurs in producing this movement, seems specially intended, in addition, to expand the pharynx. Three muscles throw their fibres around the pharynx, termed its upper, middle, and lower constrictors, which, the moment the morsel reaches the pharynx, contract upon it, and embrace it firmly. At the same instant the larynx, closing its aperture, springs forward towards the base of the tongue, under which it is in a manner concealed, the additional shield of the epiglottis being simultaneously thrown over the glottis. By this movement of the larynx, upwards and forwards, the course of the morsel across the dangerous passage is shortened. All these motions take place with such rapidity that Boerhaave said the action is convulsive. And now the food, firmly pressed by the pharynx, cannot return to the mouth, for the root of the tongue is there stopping up the passage; it cannot enter the Eustachian tubes or the nose, for the soft palate is there closing the apertures; it cannot enter the larynx, for a double guard is placed upon the glottis securing its firm closure. The food can advance in one direction only, the direction required, that which leads to the œsophagus. Well, therefore, on the contemplation of these complex structures and the consent and harmony with which they act, might Paley say, "In no apparatus put together by art do I know such multifarious uses so aptly contrived as in the natural organisation of the human mouth and its appendages. In this small cavity we have teeth of different shape; first, for cutting; secondly, for grinding; muscles most artificially disposed for carrying on the compound motions of the lower jaw by which the mill is worked; fountains of saliva springing up in different parts of the cavity for the moistening of the food while the mastication is going on; glands to feed the fountains; a muscular contrivance in the back part of the cavity for the guiding of the prepared aliment into its passage towards the stomach, and for carrying it along that passage. In the mean time, and within the same cavity, is going on other business wholly different, that of respiration and of speech. In addition, therefore, to all that has been mentioned, we have a passage opened from this same cavity of the mouth into the lungs for the admission of air, for the admission of air exclusively of every other substance; we have muscles, some in the larynx, and, without number, in the tongue, for the purpose of modulating that air in its passage, with a variety, a compass, and a precision of which no other musical intrument is capable; and, lastly, we have a specific contrivance for dividing the pneumatic part from the mechanical, and for preventing one set of functions from interfering with the other. The mouth, with all these intentions to serve, is a single cavity; is one machine, with its parts neither crowded nor confined, and each unembarrassed by the rest." It should be added, the mouth is also the immediate seat of one of the senses, and is in intimate communication with a second sense; both these senses are always excited while the principal business performed by the machine is carried on, and are necessarily excited by the very working of the machine, and the sensations induced in the natural and sound state of the apparatus are invariably pleasurable.

The food is delivered by the pharynx to the œsophagus (Fig. 81), a tube composed partly of membrane and partly of muscle. Its muscular fibres consist of a double layer, an external and an internal layer; the external has a longitudinal direction; the internal describes portions of a circle around the tube. By the contraction of the longitudinal fibres the length, and, by the contraction of the circular fibres, the diameter, of the tube is diminished. Cellular membrane envelops these layers of fibres externally, and mucous membrane covers them internally. When the tube is contracted, the mucous membrane is disposed in folds, which disappear when it is dilated, and these folds allow of the expansion of the tube without injury to the delicate tissue that lines

Fig. 86.

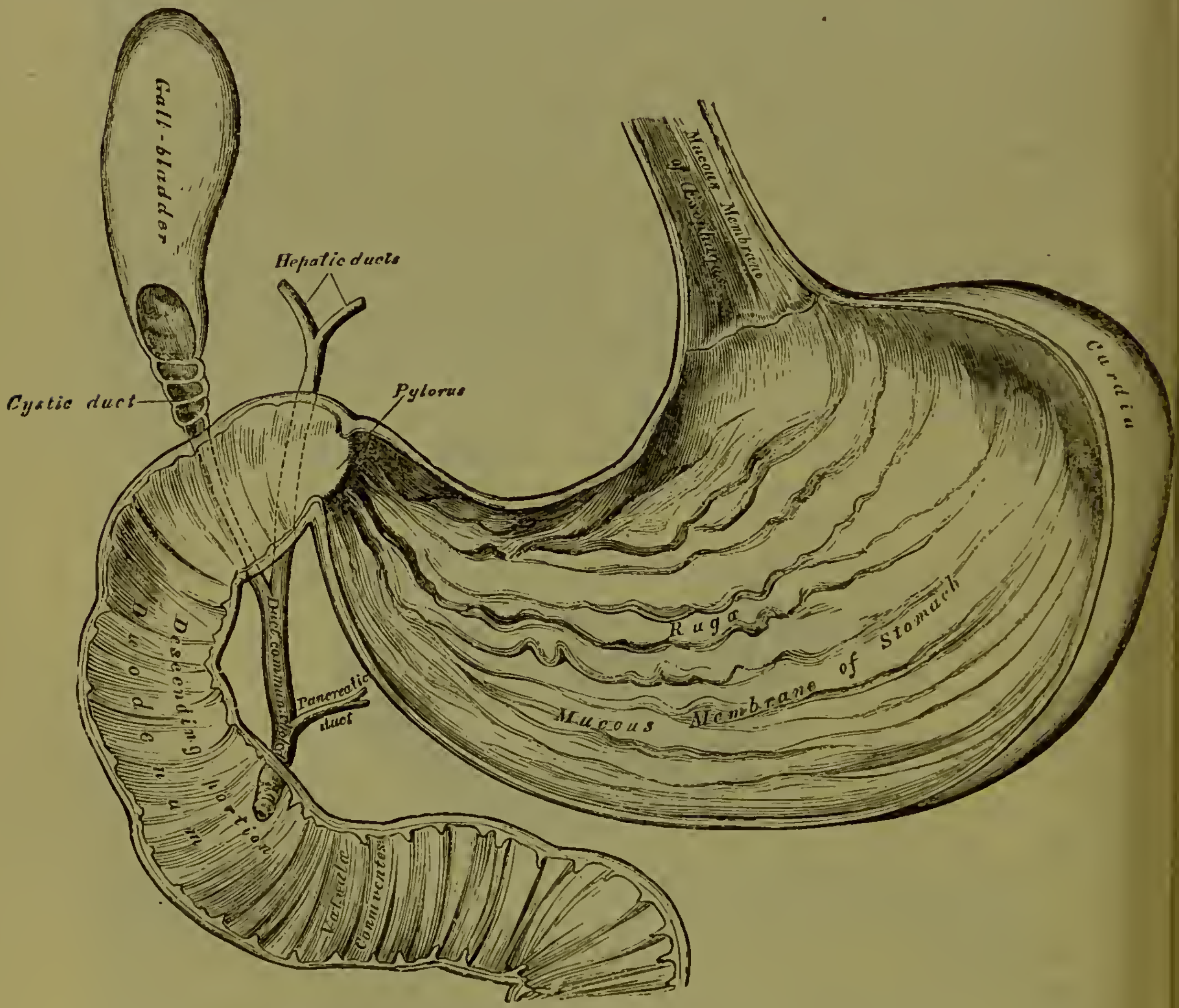


View of the stomach, with its muscular coats displayed. 1, the œsophagus terminating in the stomach; 2, the cardiac orifice; 3, the pylorus; 4, the commencement of the duodenum; 5, the large curvature of the stomach; 6, the small curvature; 7, the large extremity; 8, the small extremity; 9, the longitudinal muscular fibres; 10, the circular muscular fibres.

it. The food passes slowly along the œsophagus, urged towards the stomach, not by its own gravity, but by a force exerted upon it by the tube itself, chiefly by the contraction of its circular fibres. Delivered at length to the stomach, the food is incapable of returning into the œsophagus in consequence of the oblique direction in which the œsophagus enters the stomach, the obliquity of its entrance serving the office of a valve.

The stomach is a bag of an irregular oval shape (Fig. 86), capable in the adult of containing about three pints. It is placed transversely across the upper part of the abdomen. It occupies the whole epigastric, and the greater part of the left hypochondriac regions. Above, it is in contact with the diaphragm, on the right side with the liver, on the left with the spleen, and below with the intestines.

Fig. 87.



The mucous membrane of the stomach and duodenum, with the bile ducts.

Near the left extremity, which is much larger and considerably higher than the right (Fig. 86, 7), the œsophagus opens by an aperture called the cardiac orifice. At the right extremity, a second aperture, called the pyloric orifice (Fig. 86), leads into the first intestine.

Between the cardiac and the pyloric orifices are two curvatures, one above, called the smaller (Fig. 86, 6), the other below, termed the larger curvature (Fig. 86, 5).

Like the œsophagus, the stomach is composed of two layers of muscular fibres, the external longitudinal (Fig. 86, 9), the internal circular (Fig. 86, 10). By the contraction of the first the extent of the stomach, from extremity to extremity, is diminished, or the organ is shortened ; by the contraction of the second the extent of the stomach, from curvature to curvature, is diminished, or the organ is narrowed. During digestion, by the contraction of these muscular fibres, the capacity of the stomach is changed alternately in both directions, whence a gentle motion is communicated to the aliment, which is thus brought in succession under the influence of the agent that acts upon it.

A thin but strong membrane, derived from the peritoneum, the membrane that lines the general cavity of the abdomen, forms the external tunic of the stomach ; hence its outer covering is called the peritoneal coat.

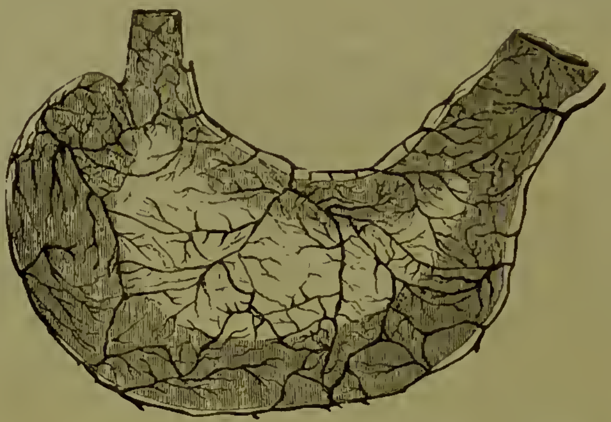
The inner or mucous coat, a direct continuation of the lining membrane of the œsophagus, is sufficiently extensive to line smoothly the stomach when it is distended ; but when it is empty and shrunken the mucous coat arranges itself in ridges called rugæ (Fig. 87), which disappear again when the stomach is full.

The mucous coat produces two distinct secretions, one a thick viscid mucus which protects the surface from the digestive solvents, and the other a clear limpid fluid called gastric juice, which consists of water holding in solution some free acid and an albuminoid material called pepsin which aid in producing the solution of the food : besides these some salts are present in small proportions, as in all the other fluids of the body. This gastric juice, as will be shown, is a highly important agent in the digestive process : it is thrown out by certain follicles formed by tubular recesses of the free surface into the substance of the mucous membrane. These are very numerous, and are largest at the pyloric end, where the tubes are divided at their blind ends. The mucus comes from all the general surface of the stomach and the mouths of the follicles.

All around the pyloric orifice (Fig. 86, 3) is placed a thick, strong, and circular muscle, termed, from its office, pylorus. It is about four times the thickness of the muscular coat of the stomach, and presents the appearance of a prominent and even projecting band. Its office is, by the contraction of its fibres, to guard and close the opening from the stomach until the aliment has been duly acted upon by the digestive fluid.

The quantity of blood sent to the stomach is greater than is spent upon any other organ except the brain. The vessels of the stomach

Fig. 88.

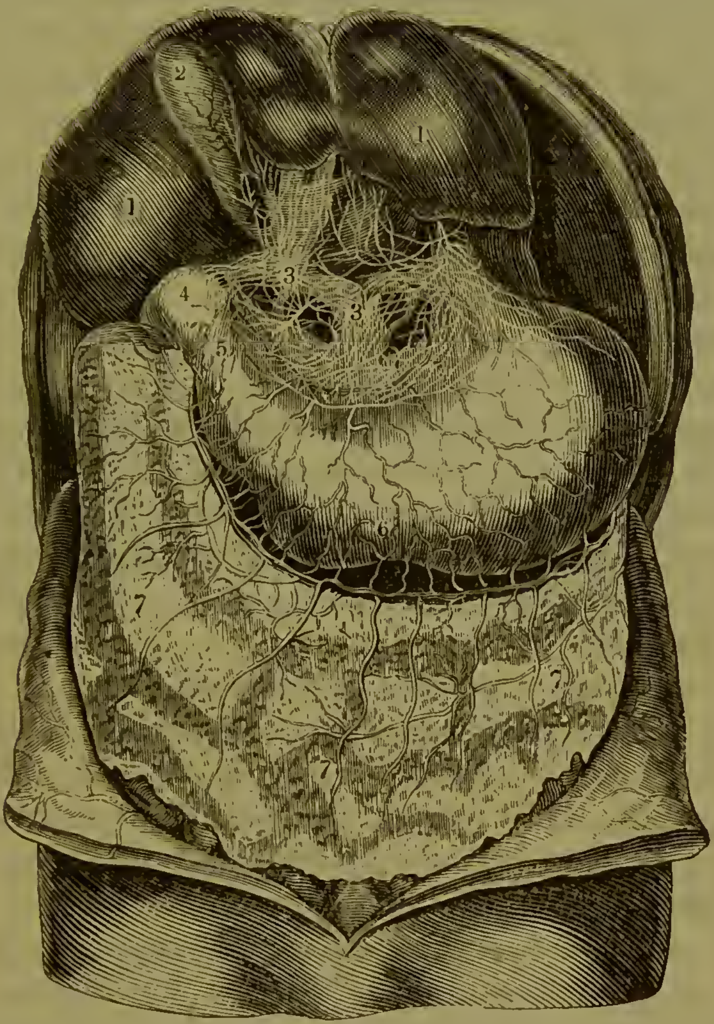


View of the stomach, showing the number and magnitude of its blood-vessels, and the mode of their distribution.

(Fig. 88) form two distinct layers, of which the external is distributed to the peritoneal and muscular coats, while the internal, after ramifying on the fine cellular tissue which unites the muscular and mucous tunics, penetrates the mucous coat, and is spent upon the villi, where it forms an exquisitely-delicate network. There is, moreover, an intimate vascular connexion between the spleen, pancreas and liver, and the stomach. The arteries which supply all these organs spring from a common trunk, and there is the freest communication between them by anastomosing branches.

Equally abundant is its supply of nerves, some of which are derived from the organic or non-sentient system, and others from the animal or sentient system. The organic nerves are spread out in countless numbers upon the great trunks of the arteries, so as to give them a complete envelop (Fig. 89, 3); these nerves, never quitting the arteries, accompany them in all their ramifications, and the fibril of the nerve is ultimately lost upon the capillary termination of the artery. It is by these organic nerves that the stomach is enabled to perform its organic functions, which, for the reason assigned, is placed beyond volition, and is without consciousness. By the nerves derived from the sentient system which mingle with the organic, the function of nutrition is brought into relation with the percipient mind, and is made part of our sentient nature. By the commixture of these two sets of nerves, derived from these two portions of the nervous system, though we have no *direct* consciousness of the digestive process—consciousness ceasing precisely at the point where the agency of volition stops, yet pleasurable sensation results from the due performance of the function. Hence the feeling of buoyancy, exhilaration, and vigour, the pleasurable consciousness to which we give the name of health, when the action of the stomach is sound: hence the depression, listlessness, and debility, the painful consciousness which we call disease, when the action of the stomach is unsound : hence, too, the influence of the mental state over the organic process; the rapidity and perfection with which the stomach works when the mind is happy—when the repast is but the occasion and accompaniment of the feast of reason and the flow of soul; the slowness and imperfection with which the stomach works when the mind is harassed with care struggling against adverse events; or is in sorrow and without hope; when the friend that sat by our side, and with whom we were wont to take sweet counsel, is gone, and therefore gone that which made it life to live.

Fig. 89.



View of the organic nerves of the stomach. 1, under surface of the liver turned up, to bring into view the anterior surface of the stomach; 2, gall-bladder; 3, organic nerves enveloping the trunks of the blood-vessels; 4, pyloric extremity of the stomach, and commencement of the duodenum; 5, contracted portion of the pylorus; 6, situation of the hour-glass contraction of the stomach, here imperfectly represented; 7, omentum.

Renovation is the primary and essential office of the stomach, and its organic nerves enable it to supply the ever-recurring wants of the system. Gratification of appetite is a secondary and subordinate office of the stomach, and its sentient nerves enable it to produce the state of pleasurable consciousness when its organic function is duly performed. By the double office thus assigned it, the stomach is rendered what Mr. Hunter named it, the centre of sympathies.

From the whole length of the great arch of the stomach, and partly also from the commencement of the duodenum (Fig. 89), the peritoneal coat of the stomach is produced, forming a thin, delicate membranous bag, called the omentum, or cawl (Fig. 89, 7). The omentum extends from the great arch of the stomach to below the umbilicus, and completely covers a large portion of the anterior surface of the abdominal viscera (Fig. 89, 7). Between the two fine membranous layers of which it is composed is contained a quantity of fat, of which substance it serves as a reservoir.

Soon after the food has entered the stomach a remarkable change takes place in the mucous membrane of the stomach. The blood-vessels become loaded with blood; the minute cells between the rugæ overflow with fluid. This fluid is the gastric juice, which is secreted by the arterial capillaries now turgid with blood. The abundance of the secretion, which progressively increases as the digestion advances, is in proportion to the indigestibility of the food, and the quietude of the body after the repast.

In the food itself no change is manifest for some time; but at length that portion of it which is in immediate contact with the surface of the stomach begins to be slightly softened. This softening slowly but progressively increases until the texture of the food, whatever it may have been, is gradually lost; and ultimately most of the solid portions of it dissolved.

When a portion of food thus acted on is examined, it presents the appearance of having been corroded by a chemical agent. The white of a hard-boiled egg looks exactly as if it had been plunged in vinegar or in a solution of potass. The softened layer, as soon as the softening is sufficiently advanced, is, by the action of the muscular coat of the stomach, detached, carried towards the pylorus, and ultimately transmitted to the duodenum; then another portion of the harder and undigested food is brought into immediate contact with the stomach, becomes softened in its turn, and is in like manner detached; and this process goes on until the whole is dissolved.

The solvent power exerted by the gastric juice is most apparent when the stomach of an animal is examined three or four hours after food has been freely taken. At this period the portion of the food first in contact with the stomach is wholly dissolved and detached; the portion subsequently brought into contact with the stomach is in the process of solution, while the central part remains very little changed.

The dissolved and detached portion of the food, from every part of the stomach flows slowly but steadily towards the pyloric extremity. The fluid, which thus accumulates in this portion of the stomach, is a new product, in which the sensible properties of the food, whatever may have been the variety of substances taken at the meal, are lost. This new product, which is termed chyme, is a homogeneous fluid, pultaceous, greyish, insipid, of a faint sweetish taste, and slightly acid.

The pylorus, obedient to the demand of the chyme, relaxes, opens, and affords to the fluid a free passage into the duodenum. As soon as the whole of the duly-prepared chyme has passed out of the stomach, the pylorus closes, and remains closed, until two or three ounces more are accumulated, when the same succession of motions are renewed with the same result; and again cease to be again renewed, as long as the process of chymification goes on.

When the stomach contains a large quantity of food, these motions are limited to the parts of the organ nearest the pylorus; as it becomes empty, they extend further along the stomach, until the great extremity itself is involved in them. These motions are always strongest towards the end of chymification.

The stomach during chymification is a closed chamber: its cardiac orifice is shut by the valved entrance of the œsophagus, and its pyloric orifice by the contraction of the pylorus.

The rapidity with which the process of chymification is carried on is different according to the digestibility of the food, the bulk of the morsels swallowed, the quantity received by the stomach, the constitution of the individual, the state of the health, and above all, the class of the animal—for it is widely different in different classes. In the human stomach in about five hours after an ordinary meal the whole of the food is probably converted into chyme.

The great agent in performing the process of chymification is the gastric juice. The evidence of this is complete; for,

1. As soon as the food enters the stomach a large quantity of blood is determined to the arteries, which secrete the gastric juice; and this fluid continues to be poured into the stomach in great abundance during the whole time the process goes on.

2. The solvent power of this fluid is demonstrated by the fact that it sometimes dissolves the stomach itself, when death takes place suddenly during the act of digestion in a sound and vigorous state of the digestive organs.

3. On introducing into the stomach alimentary substances enclosed in metallic balls perforated with holes, or in pieces of porous cloth, it is found, on removing these bodies from the stomach, after a certain time, that the alimentary substances contained in them are as completely digested as if they had been in actual contact with the surface

of the stomach; the metallic ball and the cloth remaining wholly unchanged. This experiment, which has been often performed with the same uniform result, was the first that led to the discovery of the true nature of the digestive process.

4. Though it be impossible to imitate out of the stomach all the circumstances under which the food is placed within it, yet, on procuring gastric juice from the stomachs of various animals, and mixing it with different alimentary substances, it is found not only to dissolve them, but to convert them into a pultaceous mass, closely resembling chyme. Gastric juice thus procured was put into a glass tube with boiled beef, which had been masticated; the tube was then hermetically sealed, and exposed near the fire to a uniform heat: by the side of this tube was placed another, containing the. same quantity of flesh immersed in water. In twelve hours, the flesh in the tube containing the gastric juice began to lose its fibrous structure; in thirty-five hours it had nearly lost its consistence, being reduced to a soft homogeneous pultaceous mass. It experienced no further change during the two following days. On the other hand, the flesh that had been immersed in water was putrid in sixteen hours.

Since alimentary substances under the action of the stomach present precisely the appearance exhibited by bodies exposed to the influence of chemical agents, it appears that the gastric juice not only dissolves the food, but dissolves it by a chemical agency. Its action bears no proportion to the mechanical texture of bodies, nor to any of their physical properties. It acts upon the densest membrane, dissolves even bone itself; and yet produces no effect on other substances of the most tender and delicate texture. On the skin of fruit, on the finest fibre of flax and cotton, it is incapable of making the slightest impression. In this selection of substances it perfectly resembles a chemical agent acting by chemical affinity. On certain.substances its action is unquestionably of a chemical nature. It occasions the coagulation of albuminous fluids; it prevents the accession of putrefaction; it stops the process after it has commenced. From the whole, it follows that the food in the stomach is converted into chyme by the agency of a fluid secreted by the inner surface of the stomach, and that this change is effected by a proper chemical action.

It had been long ascertained that the gastric juice contains an uncombined acid, and that if carbonate of lime be placed in a tube and introduced into the stomach, the carbonate is dissolved just as if it were put into weak vinegar. Several years ago, it was discovered by Dr. Prout that this free acid is muriatic acid. Some time after the publication of Dr. Prout's experiments, Chevreul and Leuret and Lassaigne in France obtained different results; but Tiedemann and Gmelin, professors in the university of Heidelberg, in an extended series of experiments, arrived at precisely the same conclusion as the English physiologist, and apparently without any previous knowledge of the researches of the latter. Tiedemann and Gmelin state, as the result of their experiments, that the clear ropy fluid, or the gastric juice obtained from the stomach some time after it had been without food, is nearly or entirely destitute of acidity; that the presence of food, or indeed of any stimulus to the mucous membrane, causes the gastric juice to become distinctly acid; that this acidity increases according to the indigestibility of the food; that the quantity of acid poured out is very copious; that it consists partly of muriatic and partly of acetic acid; and that both these acids are efficient agents in the process of digestion. Dr. Prout, who had also recognised the presence of acetic acid, is of opinion that its formation is an accidental occurrence not necessary to digestion nor conducive to it; but is either derived from the aliment, or is the result of irritation or disease. He contends that the muriatic acid is the efficient digestive agent.

The still more recent experiments of Braconnot appear to have set this matter at rest, and to have proved, beyond all controversy, that the stomach, when stimulated by the presence of food or other foreign agents, possesses the power of secreting free muriatic acid in great quantity; and that it is by this acid that the solution of the food is effected. It is even found that muriatic acid is capable of digesting alimentary substances out of the body. It had been long known, that if meat and gastric juice be enclosed in a tube and kept at the temperature of the human body, a product is obtained closely resembling chyme. M. Blondelot, a physician at Nancy, showed that the same result may be obtained by the digestion of the muscular fibre, in dilute muriatic acid. In both cases the muscular fibre retains its form and its original fibrous texture; but on the slightest motion it divides into an insoluble mass, perfectly homogeneous and similar to the chyme of the stomach;* a very close approximation to the actual digestive process, more especially when it is considered that it is not possible to imitate out of the stomach several circumstances materially influencing chemical action under which the food is placed within the stomach.

Muriatic acid, the chemical agent by which the stomach dissolves the food, is probably obtained from the muriate of soda (common salt) contained in the blood. The soda, the basis of the salt, would appear to be retained in the blood, to preserve the alkaline condition essential to the maintenance of the sound constitution of the blood, while the muriatic acid, disengaged from the soda in the process of secretion, is poured into the stomach to act upon the food.

A remarkable confirmation of the correctness of the general conclusions to which observation and experiment had thus enabled physiologists to arrive, is afforded by the case of a young soldier in the American army, of the name of Alexis St. Martin, who received a wound on the left side by the accidental discharge of a musket. The charge, which consisted of duck-shot, and which was received at the distance of one yard from the muzzle of the gun, entered the side posteriorly in an oblique direction, forward and inward; blew off the integument and muscles to the size of a man's hand; fractured and carried away the anterior half of the sixth rib; fractured the fifth rib; lacerated the lower portion of the left lobe of the lungs; lacerated the diaphragm, and perforated the stomach.

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* Dr. R. Thomson, "British Annals of Medicine," No. 13.

Violent fever and extensive sloughing of the parts injured ensued, and the life of the young man was often in jeopardy, but he ultimately recovered. At the distance of about a year from the date of the accident, the injured parts had all become sound, with the exception of the perforation into the stomach, which never closed, but left an aperture permanently open, two inches and a half in circumference. This aperture was situated about three inches to the left of the cardia, near the left superior termination of the great curvature. For some time the food could be retained only by constantly wearing a compress and bandage; but at length a small fold of the mucous coat of the stomach appeared, which increased until it completely filled the aperture and acted as a valve, so as effectually to prevent any efflux from within, while it admitted of being easily pushed back by the finger from without: when the stomach was nearly empty, it was easy to examine its cavity to the depth of five or six inches by artificial distension; but, when entirely empty, the stomach was always contracted on itself, and the valve generally forced through the orifice, together with a portion of the mucous membrane equal in bulk to a hen's egg.

It chanced that the admirable opportunity thus afforded of bringing the process of digestion, as far as it is carried on in the stomach, under the cognizance of sense, occurred to an observant and philosophical mind, and it was not lost.* The following are some of the curious and instructive phenomena observed.

The inner coat of the stomach, in its natural and healthy state, is of a light or pale-pink colour, varying in its hues according to its full or empty state. It is of a soft or velvet-like appearance, and is constantly covered with a very thin, transparent, viscid mucus, lining the whole interior of the organ.

Immediately beneath the mucous coat appear small spheroidal, or oval-shaped glandular bodies, from which the mucous fluid appears to be secreted.

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* "Experiments and Observations on the Gastric Juice, and the Physiology of Digestion." By W. Beaumont, M.D., Surgeon in the U. S. Army. Boston. 1834.

By applying aliment or other irritants to the internal coat of the stomach, and observing the effect through a magnifying glass, innumerable minute lucid points, and very fine nervous or vascular papillæ are seen arising from the villous membrane, and protruding through the mucous coat, from which distils a pure, limpid, colourless, slightly viscid fluid. This fluid, thus excited, is invariably distinctly acid. The *mucus* of the stomach is less fluid, more viscid or albuminous, semi-opaque, sometimes a little saltish, and does not possess the slightest character of acidity. On applying the tongue to the mucous coat of the stomach in its empty, unirritated state, no acid taste can be perceived. When food or other irritants have been applied to the villous membrane and the gastric papillæ excited, the acid taste is immediately perceptible. The invariable effect of applying aliment to the internal, but exposed part of the gastric membrane, is the exudation of the solvent fluid from the papillæ. Though the aperture of these vessels cannot be seen even with the assistance of the best microscopes, yet the points from which the fluid issues are clearly indicated by the gradual appearance of innumerable very fine lucid specks rising through the transparent mucous coat, and seeming to burst and discharge themselves upon the very points of the papillæ, diffusing a limpid thin fluid over the whole interior gastric suface.

The fluid so discharged is absorbed by the aliment in contact; or collects in small drops, and trickles down the sides of the stomach to the more depending parts, and there mingles with the food, or whatever else may be contained in the gastric cavity. This fluid, the efficient cause of digestion, the true gastric juice, is secreted only when it is needed; it is not accumulated in the intervals of digestion, to be ready for the next meal; it is seldom if ever discharged from its proper secreting vessels, except when excited by the natural stimulus of aliment, the mechanical irritation of tubes, or other excitants. When aliment is received, the juice is given out in exact proportion to its requirements for solution, except when more food has been taken than is necessary for the wants of the system.

On collecting this fluid, which it was easy to obtain, it was found to be transparent, inodorous, saltish, and acidulous to the taste; it consisted of water, containing free muriatic and acetic acids, phosphates and muriates, with bases of potass, soda, magnesia, and lime, together with an animal matter soluble in cold, but insoluble in hot water.

When a portion of liquid aliment, as a few spoonfuls of soup, were introduced into the stomach at the external orifice, the rugæ (Fig. 87) immediately closed gently upon it; gradually diffused it through the gastric cavity, and prevented the entrance of a second quantity till this diffusion was effected; then relaxation again took place, and admitted of a further supply. When solid food was introduced in the same manner, either in large pieces or finely divided, the same gentle contraction and grasping motions were excited, and continued from fifty to eighty seconds, so as to prevent more from being introduced, without considerable force, till the contraction was at an end.

When the position of the body was such that the cardiac portion of the stomach was brought into view, and a morsel of food was swallowed in the natural mode, a similar contraction of the stomach, and closing of its fibres upon the bolus was invariably observed to take place; and till this was over, a second morsel could not be received without a considerable effort. Hence, in addition to the other purposes accomplished by mastication, insalivation, and deglutition, it is probable that these operations answer the further use of duly regulating the time for the admission of successive portions of the food into the stomach.*

On watching the phenomena that take place on the contact of a portion of food with the stomach, the circumstances described are seen; the change in the mucous coat from a pale-pink to a deep-red colour, in consequence of the enlargement of the blood-vessels and their admission of a greatly increased number of red particles; the undulating motion of the stomach, in consequence of the contraction of its muscular fibres, excited by the stimulus of food; the distillation of the gastric juice from the enlarged and excited papillæ; the continuous flow of this fluid until the complete solution of the food, when food is present; and, on the contrary, the cessation of this discharge in a short time when it is produced by a mechanical irritant, as the bulb of a thermometer, although at first the gastric juice distil from the papillæ, from the contact of such an irritant, just as when excited by the contact of food.

On collecting the gastric juice and placing it in contact with an alimentary substance out of the stomach, its solution takes place more slowly, but not less completely, than when retained in the stomach. An ounce of this fluid was placed in a vial with a piece of boiled, recently salted beef, weighing three drachms; the vial was then tightly corked, and immersed in water, raised to the temperature of 100°, previously ascertained to be the ordinary heat of the stomach. In forty minutes the process of solution had commenced on the surface of the beef. In fifty minutes the texture of the beef began to loosen and separate. In sixty minutes an opaque and cloudy fluid was formed. In one hour and a half the muscular fibres hung loose and unconnected, and floated about in shreds in the more fluid matter. In three hours the muscular fibres had diminished about one half. In five hours only a few remained undissolved. In seven hours the muscular texture was no longer apparent; and in nine hours the solution was completed.

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* See Dr. Andrew Combe on the "Physiology of Digestion," in whose work a full detail of this instructive case is given. See also "Mayo's Outlines of Physiology."

At the commencement of this experiment a piece of the same beef of equal weight and size was suspended within the stomach by means of a string. On examining this portion of beef at the end of half an hour, it was found to present precisely the same appearance as the piece in the vial; but on the removal of the string at the end of an hour and a half the beef had been completely dissolved, and had disappeared, making a difference of result in point of time of nearly seven hours. In both, the solution began on the surface, and agitation accelerated its progress by removing the external coating of chyme as fast as it was formed.

An ordinary dinner having been taken, consisting of boiled salted beef, bread, potatoes, and turnips, with a gill of pure water for drink, a portion of the contents of the stomach was drawn off into an open-mouthed vial, twenty minutes after the meal. The vial was placed in a water-bath, maintained steadily at a temperature of 100°. It was continued in this temperature for five hours. At the end of that time the whole contents of the vial were dissolved. On comparing the solution with an equal quantity of chyme taken from the stomach, little difference could be distinguished between the two fluids, excepting that it was manifest that the digestive process had proceeded somewhat more rapidly in, than out of the stomach. The food, in this experiment, after having remained in contact with the stomach for the space of twenty minutes, had imbibed a sufficient quantity of gastric juice to complete its solution.

Fifteen minutes after half a pint of milk had been introduced into the stomach, it presented the appearance of a fine loosely-coagulated substance mixed with a semi-transparent whey-coloured fluid. A drachm of warm gastric juice poured into two drachms of milk at a temperature of 100°, produced a precisely similar appearance in twenty minutes. In another experiment, when four ounces of bread were given with a pint of milk, the milk was coagulated and the bread reduced to a soft pulp in thirty minutes, and the whole was completely digested in two hours.

When the albumen or white of two eggs was swallowed on an empty stomach, small white flakes began to be seen in about ten or fifteen minutes, and the mixture soon assumed an opaque whitish appearance. In an hour and a half the whole had disappeared. Two drachms of albumen mixed with two of gastric juice out of the stomach underwent precisely the same changes, but in a somewhat longer time.

In the human stomach, according to the subject of these experiments, the ordinary course and direction of the food are first from right to left along the small arch, and thence through the large curvature from left to right. The bolus as it enters the cardia turns to the left, passes the aperture, descends into the splenic extremity, and follows the great curvature towards the pyloric end. It then returns in the course of the smaller curvature, makes its appearance again at the aperture, in its descent into the great curvature, to perform similar revolutions. These revolutions are completed in from one to three minutes. They are probably induced in a great measure by the circular or transverse muscles of the stomach, as is indicated by the spiral motion of the stem of the thermometer, both in descending to the pyloric portion, and in ascending to the splenic. These motions are slower at first than after chymification has considerably advanced. The whole contents of the stomach, until chymification be nearly complete, exhibit a heterogeneous mass of solids and fluids, hard and soft, coarse and fine, crude and chymified; all intimately mixed, and circulating promiscuously through the gastric cavity like the mixed contents of a closed vessel, gently agitated or turned in the hand.

The chambers in which the remaining part of the digestive process is carried on are much less accessible, and no such favourable opportunity as that enjoyed by Dr. Beaumont has occurred of rendering their operations manifest to the eye. Nevertheless, the researches of physiologists have succeeded in disclosing, with almost equal exactness and certainty, the successive changes which the food undergoes even in these more hidden organs, that admit of no exposure during life without extreme danger.

The chyme on passing through the pylorus is received into a chamber which forms the first portion of the small intestines. The small intestines, taken together, constitute a tube about four times the length of the body.* This tube is conical, the base of the cone being towards the pylorus, and its apex at the valve of the colon, where the small intestines terminate in the large. From the pylorus to the valve of the colon the small intestines diminish in capacity, in thickness, in vascularity, in the size of the villi, and in the depth and number of the valvulæ conniventes.

The first portion of the small intestine is termed the duodenum. It is about twelve inches in length; and, unlike the stomach, which is capable of considerable motion, it is closely tied down to the back by the peritoneum, which imperfectly covers it. The rest of the small intestine is divided into two portions—the upper two-fifths of which are termed jejunum, and the three lower ilium.

The duodenum, the chamber which receives the chyme from the pylorus, is a second stomach, which carries on the process commenced in the first. It is assisted in the performance of its function by two organs of considerable magnitude, the pancreas and the liver.

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* Described by some anatomists as six times, and in children, from their smaller stature, ten times, the length of the body, *i.e.*, measuring from head to heels.

The pancreas is a conglomerate gland (Figs. 51 and 92), of an elongated form, placed in the epigastric region, lying transversely across it, immediately behind the stomach, and resting upon the spinal column. Its right extremity is attached to the duodenum, and its left to the spleen. In external appearance it resembles the salivary glands, but it is of much larger size, and its weight, from four to six ounces, is three times greater than that of all the salivary glands together. It secretes a peculiar fluid called the pancreatic juice, which is carried into the duodenum by a tube named the pancreatic duct (Fig. 87), which opens into the duodenum about four or five inches from its pyloric end.

The liver, the largest and heaviest gland in the body, weighing about four pounds, is placed chiefly in the right hypochondriac region (Fig. 89); but a portion of it extends transversely across the epigastric, into the left hypochondriac region. Its upper surface is in contact with the diaphragm; its under surface with the pyloric extremity of the stomach (Fig. 92), and its margin can be felt under the edges of the ribs of the right side.

It has been stated that the fluid secreted by the liver, unlike that formed by any other organ of the body, is elaborated from venous blood, derived from the veins of the digestive organs, and that these veins uniting together, form a common trunk called the vena portæ, which penetrates the liver and ramifies through it in the manner of an artery. Galen long ago compared this venous system to a tree whose roots are dispersed in the abdomen, and its branches spread out through the liver. A comparatively small artery, called the hepatic, nourishes the liver; the ultimate divisions of these arteries likewise terminate in the vena portæ. The ultimate branches of the vena portæ terminate in a system of veins, called the hepatic, which like ordinary veins return the blood to the right side of the heart; a system of tubes, termed the biliary ducts, receive the fluid secreted by the capillary branches of the vena portæ. This fluid is the bile. The biliary ducts uniting from all parts of the liver by innumerable branches, at length form a single trunk termed the hepatic duct (Fig. 87, hep. duct), which carries the bile partly to the gall bladder (Fig. 87) by a duct called the cystic, and partly to the duodenum (Fig. 87) by a duct named the choledoch, a common trunk formed by the union of the cystic with the hepatic. The choledoch duct opens into the duodenum at the same point as the pancreatic (Fig. 87), and generally by a common orifice.

The duodenum, on receiving the chyme from the stomach, transmits it slowly along its surface. The kind of motion by which the chyme is borne along the surface of the duodenum is perfectly analogous to that by which it is transmitted from the stomach to the duodenum, irregular, sometimes in one direction, and sometimes in another, at one time commencing in one part of the organ, at another time in another, always slow, but ultimately progressive.

As the chyme slowly advances through the upper part of the duodenum, the biliary and the pancreatic juices slowly distil into the lower portion of the organ.

No appreciable change takes place in the chyme until it reaches the orifice of the choledoch duct; but as soon as it comes in contact with this portion of the duodenum, the chyme suddenly loses its own sensible properties, and acquires those of the bile, especially its colour and bitterness. But these properties are not long retained; a spontaneous change soon takes place in the compound. It separates into a white fluid and into a yellow pulp. The white fluid is the nutritive part of the aliment; the yellow pulp is the excrémentitious matter.

This white fluid, the proper product of the digestive process, as far as it has yet advanced, is called chyle. If any portion of oil or fat have been contained in the food, the chyle is of a milk-white colour; if not, it is nearly transparent. It is of the consistence of cream, and it bears a close resemblance to cream in its sensible properties. It differs from chyme in being of a whiter colour, more pellucid, and of a thicker consistence: it differs also in its chemical nature, for, whereas chyme is acid, chyle is alkaline.

Three fluids are mixed with the chyme in the duodenum, each of which contributes to the conversion of the chyme into chyle. First, the secretion of the duodenum itself, a solvent analogous to the gastric juice. Secondly, the secretion of the pancreas, a watery fluid holding in solution highly important principles, namely, a large quantity of albumen, a matter resembling casein, and different salts. Thirdly, the secretion of the liver, a compound fluid, consisting of water, mucus, and several peculiar animal matters, namely, resin, cholesterine, saponaceous soda, salts of the proper biliary acids (tauro and glyco-cholic), colouring matters, osmazome, casein, and many salts.

There cannot be a question that the secretion of the duodenum has a solvent power over the chyme analogous to that of the gastric juice. Some physiologists indeed maintain that the juice poured out from the inner surface of the duodenum is as powerful a solvent as the gastric juice. It is certain that substances which have escaped chymification in the stomach undergo that process in the duodenum, and that there is the closest analogy between the action of the duodenum on the chyme and that of the stomach on the crude food.

The pancreatic secretion contains an animal substance very like the ptyalin of saliva, and which possesses the same power of dissolving starchy matter; it further acts on the fatty matter of the chyme, *emulsifying* or dividing the fat into exceedingly fine particles so minute that the high powers of the microscope are unable to detect them individually; these diffused give the milkiness to the chyle, and through their smallness they can pass within the absorbent villi.

The bile, the most complex secretion in the body, accomplishes manifold purposes.

1. Like the pancreatic juice, bile has the property of emulsifying fat; consequently, when oily or fatty matters are contained in the food, it powerfully assists in converting these substances into chyle.

2. The excrementitious portion of the bile is highly stimulant. The contact of its bitter resin with the mucous membrane of the intestines excites the secretion of that membrane; hence the extreme dryness of the excrementitious matter when the choledoch duct of an animal has been tied; and hence the same dryness of this matter in jaundice, when the bile, instead of being conveyed by its appropriate duct into the duodenum, is taken up by the absorbents, poured into the blood, and distributed over the system.

3. The bitter resin of the bile stimulates to contraction the fibres of the muscular tunic of the intestines: by the contraction of these fibres the excrementitious matter is conveyed in due time out of the body; hence the constipated state of the bowels invariably induced when the secretion of the bile is deficient, or when its natural course into the intestines is obstructed.

4. The excrementitious portion of the bile exerts an antiseptic influence over the excrementitious portion of the food during its passage through the intestines. In animals in which the choledoch duct has been tied, the excrementitious portion of the food is invariably found much further advanced in decay than in the natural state. This is also uniformly the case in the human body in proportion as the secretion of the bile is deficient, or its passage to the intestine is obstructed.

Such appear to be the real purposes accomplished by the bile in the process of digestion. Several uses have been assigned to it, in promoting this process, which it does not serve. Seeing the instantaneous change wrought in the chyme on its contact with the bile, it was reasonable to suppose that the main use of the bile was to convert chyme into chyle, a purpose apparently of sufficient importance to account for the immense size of the gland constructed for its elaboration. The soundness of this conclusion appeared to be established by direct experiment. Mr. Brodie placed a ligature around the choledoch duct of an animal: after the operation the animal ate as usual: on killing the animal some time after it had taken a meal, and examining the body immediately after death, it was clear that chymification had gone on in the stomach just as when the choledoch duct was sound, but no chyle appeared to be contained either in the intestines or in the lacteals. In the lacteals there was found only a transparent fluid, which was supposed to consist of lymph and of the watery portion of the chyme. Mr. Brodie's experiments seemed to be confirmed by those of Mr. Mayo, who arrived at the conclusion, that when the choledoch duct is tied, and the animal is examined at various intervals after eating, no trace whatever of chyle is discoverable in the lacteal vessels. But these experimentalists inferred that no chyle existed in the intestines or lacteals, because there was present no fluid of a milk-white colour, a colour not essential to chyle, but dependent on the accident of oily or fatty matter having formed a portion of the food. These experiments have been repeated in Germany by Tiedemann and Gmelin, and in France by Leuret and Lassaigne, who have invariably found, after tying the choledoch duct, nearly the same chylous principles, with the exception of those derived from the bile, as in animals perfectly sound; and the English physiologists have since admitted that their German and French collaborateurs have arrived at conclusions more correct than their own.

The bile consists then of two different portions: a highly animalized portion, which combines with the chyme and exalts its nature by approximating it to the condition of the blood; and an excrementitious portion, which, after accomplishing certain specific uses, is carried out of the system with the undigested matter of the food. The excrementitious portion of the bile, namely, the resin, the fat, the colouring principle, the mucus, the salts, constitute by far the largest portion of it. These constituents of the bile for the most part contain a very large proportion of carbon and hydrogen, and the reasons have been already fully stated which favour the conclusion that the elimination of these substances under the form of bile is one most important mode of maintaining the purity of the blood, and that the liver is thus a proper respiratory organ, truly auxiliary to the lungs. It is a beautiful arrangement, and like one of the adjustments of nature, that the bile, the formation of which abstracts from the blood so large a portion of carbon and hydrogen as to maintain the purity of the circulating mass and to counteract its putrescent tendency, acts on the excrementitious portion of the food, always highly putrescent, as a direct and powerful antiseptic; that the very matter which is eliminated on account of the putrid taint it communicates to the blood, on its passage out of the body, stops the putrefaction of the substances which have been ministering to the replenishment of the blood.

The chyle, thick, glutinous, and adhesive, attaches itself with some degree of tenacity to the mucous surface of the duodenum. Nevertheless, by the successive contractions of the muscular fibres of the duodenum the fluid is slowly but progressively propelled forwards. The separation of the excrementitious matter becomes more complete, and consequently the chyle more pure as it advances, until, having traversed the course of the duodenum, it enters the second portion of the small intestines, the jejunum.

The jejunum, so called because it is commonly found empty, and the ilium, named from the number of its convolutions, on account of their great length are provided with a distinct membrane to support them, and to retain them in their situation, termed the mesentery.

The mesentery is a broad membrane composed of two layers of peritoneum. Between these two layers, at one extremity of the duplicature, is placed the intestines, while the other extremity is attached to the spinal column. The mesentery being much shorter than the intestines, the intestines are gathered or puckered upon the membrane, by which beautiful mechanical contrivance they are held in firm and close contact with each other, yet their convolutions cannot be entangled, nor can they be shaken from their place by the sudden and often violent movements of the body. It sometimes happens, in consequence of disease, that the convolutions of the intestines are glued together by the effusion of lymph, and then the most trifling causes are capable of producing the severest symptoms of obstruction in the bowels.

The internal surface of the small intestines is distinguished—

1. By the number of the mucous glands, which may be seen by a magnifying glass to consist partly of a prodigious number of the minutest follicles, not collected in groups, but equally scattered throughout; and partly of glands of a larger dimension, disposed in groups at particular parts of the canal.

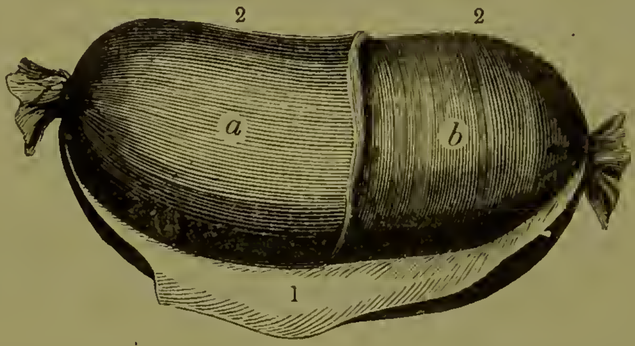
2. By the presence of the villi, of which there are about four thousand to the surface of a square inch. The villi of the small intestine are composed of arteries, veins, and there is added a new vessel, the absorbent of the chyle, the lacteal, so named from the milk-like chylous fluid which it contains.

3. By the great extension of the mucous coat obtained by the disposition of the membrane into the folds called valvulæ conniventes (Fig. 87). These folds, which rarely extend through the whole circle of the intestine, are often joined by communicating folds. The folds are broadest in the middle, and narrowest at the extremities. In general, they are about a live and a half broad. One edge of the fold is loose, but the other is fixed to the intestine. The office of these folds is, first, without increasing space, to extend surface for the distribution of the villi; and, secondly, to retard the flow of the chyle, by opposing to its descent valves so constructed and disposed as,

without arresting its progress, to moderate and regulate its course, in order that time may be allowed for its absorption.

The onward flow of the chyle through the course of the small intestines is effected by the action of the double layer of muscular fibres, the circular and the longitudinal fasciculi which compose its muscular coat (Fig. 90). The disposition of the muscular fibres of the alimentary canal in general, and of this part of it in particular, deserves special notice. The ordinary arrangement and action of muscular fibres would not have produced in this case the kind and degree of motion required. The muscular fibres that compose the ventricles of the heart are so accumulated and disposed, that their contraction originates, and communicates energetic impulse. The muscles of the arm are so accumulated and disposed that their contraction originates the like energetic impulse. Muscles so accumulated in the alimentary canal would have produced motion, indeed, but motion not only not accomplishing the end in view, but directly defeating it. In order to obtain the kind and degree of motion in this case required, the firm and thick muscle is attenuated into minute, delicate, and thready fibres, not concentrated in a bulky mass, so as to obtain by their accumulation a great degree of force, but spread out in such a manner as to form a thin and almost transparent coat. The tender fibres composing this delicate coat, by their contraction, produce two alternate, gentle, almost constant motions, called the peristaltic, from its resemblance to the motion of the earth-worm, and the antiperistaltic. By the peristaltic action motion is begun at once in several parts of the canal. Whenever the chyle is applied in a certain quantity to any part of the intestines, that part contracts, and makes a firm point, towards which the portions both above and below are drawn, by means of the longitudinal fibres which shorten the canal, and at the same time dilate the under part. By the antiperistaltic action, which is the

Fig. 90.



View of the outer coats of the small intestine. 1, peritoneal coat reflected off; 2, muscular coat, consisting of—*a*, longitudinal fibres; *b*, circular fibres.

exact reverse of the former, the chyle is turned over and over, and exposed to the orifices of the lacteal vessels; while, by the motion of the chyle forwards and backwards, and backwards and forwards, produced by these two actions constantly alternating with each other, its slow, gentle, but ultimately progressive course is secured.

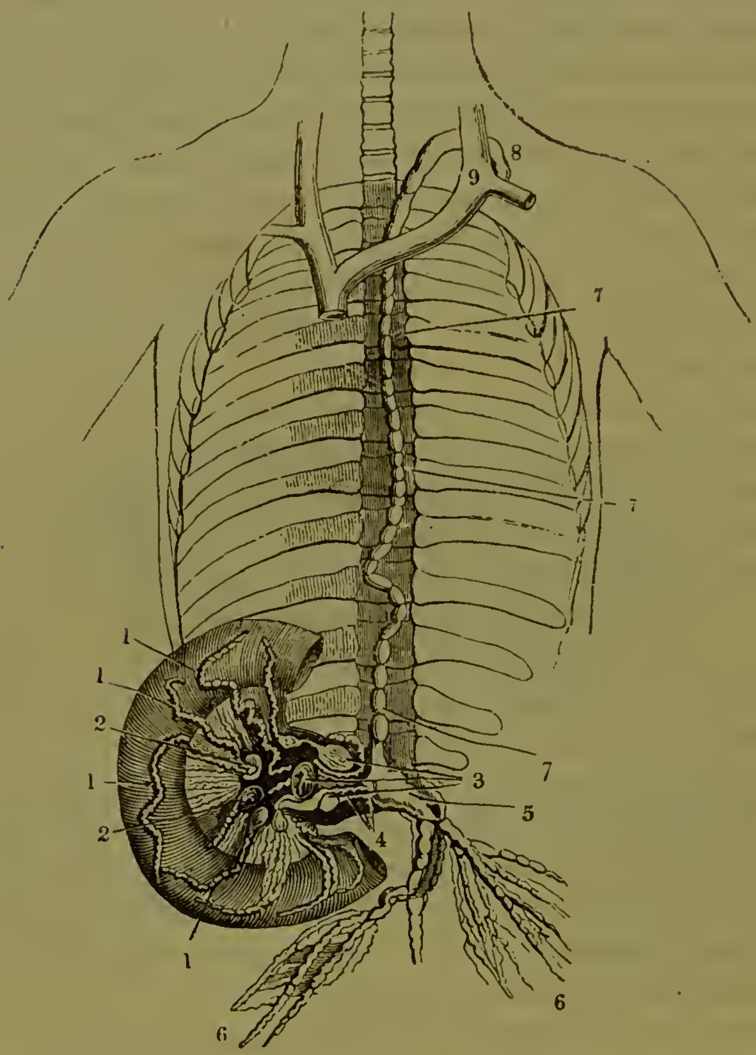
The chyle thus gently moved along the extended surface of the jejunum and ilium, and still in its course acted upon in some degree by the secretions poured out upon the mucous membrane, successively disappears, until at the termination of the ilium there is scarcely any portion of it to be perceived. It is taken up by the vessels termed lacteals.

The lacteal vessels arise in the villi, being, probably, continuous with the interstices between the blood-vessels, &c., which compose their substance. They are minute, pellucid tubes, wholly countless in number, are composed of membranous coats so thin and transparent that the milky colour of their contents, from which they derive their name, is visible through them, and yet they are firm and strong. They present a jointed appearance (Fig. 91). Each joint denotes the situation of the valves with which they are provided, and which are placed at regular distances along their entire course. These valves, which are generally placed in pairs (Fig. 94), consist of a delicate fold of membrane of a semilunar form, one edge of which is fixed to the side of the vessel, while the other lies loose across its cavity. So firm is this membrane, and so accurately does it perform the office of a valve, that even after death it is capable of supporting a column of mercury of considerable weight without giving way, and of preventing a retrograde course of the fluid. The lacteals are provided with muscular fibres, they are contractile, and it is perhaps partly by this contractile power that their contents are moved.

If the mucous coat of the small intestines be examined some hours after a meal, the lacteals are seen turgid with chyle, covering its entire surface. These vessels, which are sometimes of such magnitude and in such numbers as entirely to conceal the ramifications of the blood-vessels, unite freely with each other, and form a network, from the meshes of which proceed branches which, successively uniting, form branches of a larger size. These larger branches leave the mucous coat and pass for some way between the mucous and the muscular tunics: at length they perforate the muscular coat, when, from having been on the inside of the intestine, they get on the outside of it, and are included, like the intestine itself, between the layers of the mesentery. All the different sets of lacteals converging and uniting together, form an exceedingly complicated plexus of vessels within the fold of the mesentery. Radiating from this plexus, the lacteals advance until they reach the glands.

called, from their being placed between the fold of the mesentery, the mesenteric (Fig. 91, 2, 3); rounded, oval, pale-coloured bodies, consisting of two sets, arranged in a double row; the set nearest the intestine (Fig. 91, 2) being considerably smaller than the succeeding set (Fig. 91, 3.)

Fig. 91.



View of the course of the thoracic duct from its origin to its termination. 1, lacteal vessels emerging from the mucous surface of the intestines; 2, first order of mesenteric glands; 3, second order of mesenteric glands; 4, the great trunks of the lacteals emerging from the mesenteric glands, and pouring their contents into, 5, the receptacle of the chyle; 6, the great trunks of the lymphatic or general absorbent system, terminating in the receptacle of the chyle; 7, the thoracic duct; 8, termination of the thoracic duct at, 9, the angle formed by the union of the internal jugular vein with the subclavian vein.

On reaching the first series of glands, the lacteals penetrate the substance of the gland, in the interior of. which they lose their proper coats, and become continuous with freely communicating passages, whose walls are lined with epithelial corpuscles, which resemble the particles that are found in the chyle after it has been through the gland, so that these probably come from this source. Blood-vessels are richly spread out in the interior of the glands, and come into near relation with the chyle that passes through them. Emerging from the first series of glands, the lacteals proceed on their course to the second series, which they penetrate, and in the interior of which they are disposed, as in the first set. On passing out of this second series of glands, the lacteals unite together, and compose successively larger and larger branches, until at length they form two or three trunks (Fig. 91, 4), which terminate in the small oval sac (Fig. 91, 5), termed the receptacle of the chyle (receptaculum chyli).

In this oval sac or receptacle of the chyle, which rests upon the second or the first lumbar vertebra, also terminate the trunks of the general absorbent vessels of the system, called from the *lymph* or the pellucid fluid which they contain, lymphatics, as the lacteals are named from the lactitious or milky appearance of their contents.

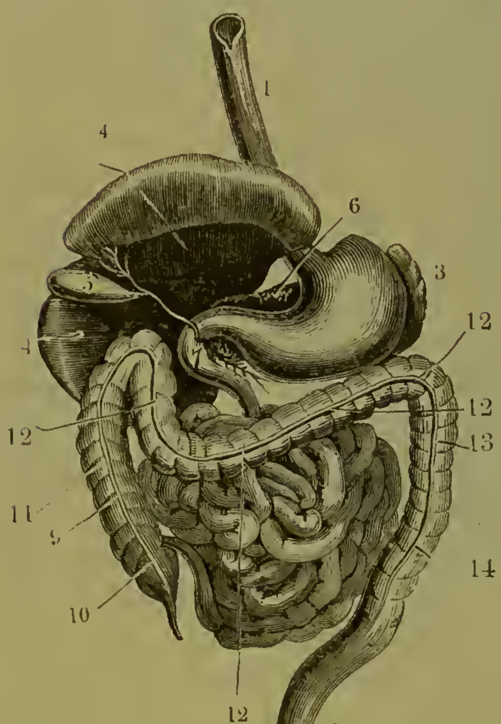
The receptacle of the chyle produced forms the thoracic duct (Fig. 91, 7), a canal about three lines in diameter. This tube rests upon the spinal column, ascends on the right side of the aorta, passes through the aortic opening in the diaphragm, and enters into the chest. Here it forms a transparent tube about the size of a crow-quill; it rests upon the bodies of the dorsal vertebræ; it continues to ascend still on the right side of the aorta, until it reaches the sixth or fifth dorsal vertebra, when changing its direction, it passes obliquely over to the left side. From this point it continues its course upwards, on the left side of the neck, as high as the sixth cervical vertebra; when suddenly turning forwards and a little downwards, it terminates its course in the angle formed by the union of the internal jugular with the subclavian vein (Fig. 91, 8, 9). At its termination in these great venous trunks are placed two valves, which prevent alike the return of the chyle, and the entrance of the blood into the duct.

This account of the course of the thoracic duct is a description of the course of the chyle. Performing a double, circuitous, and slow circulation through the minute convoluted tubes of which the double series of mesenteric glands are composed, the chyle, in its receptaculum, is mixed with the contents of the lymphatic vessels, lymph, that is, organic matter brought from every surface and tissue of the body. Both fluids, chyle and lymph, mixed and mingled, flow together into the thoracic duct, by which in the course traced they are poured into the blood, just as the venous torrent is rushing to the heart.

Thus, the final product of digestion, the chyle; particles of organised matter, the lymph; and venous blood, that is, blood which has already circulated through the system commingled, flow together to the right heart, by which they are transmitted to the lungs, where all these different fluids are converted into one substance, arterial blood, to be by the left heart sent out to the system for its support.

While these processes are going on, another and a very important function is performed by the remaining portion of the alimentary canal. It is the office of this part of the apparatus to carry out of the body that portion of the aliment which is incapable of being converted into chyle. The preparation of the excrementitious part of the aliment for its expulsion constitutes the process of fecation. The organs in which this process is carried on, and by which the excrementitious matter, when duly prepared for its removal, is conveyed from the body, are the large intestines.

Fig. 92.



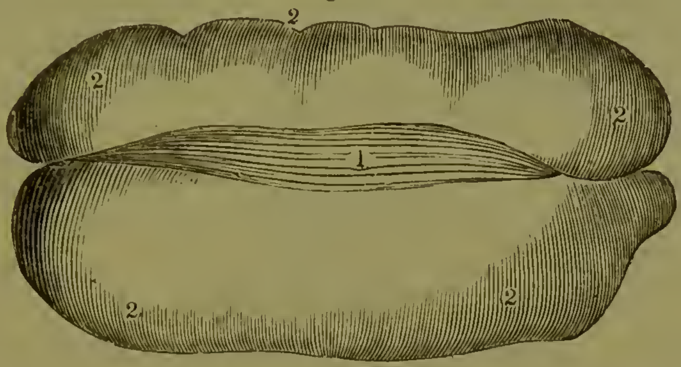
View of the abdominal portion of the digestive organs. 1, œsophagus; 2, stomach; 3, spleen; 4, liver; 5, gall-bladder with its ducts; 6, pancreas with its duct; 7, duodenum; 8, small intestines; 9, large intestines dividing into, 10, cæcum; 11, ascending colon; 12, arch of the colon; 13, descending colon; 14, sigmoid flexure, here imperfectly represented; 15, rectum.

The large intestines (Fig. 92, ascending and descending colon) consist of the cæcum, the colon, and the rectum. The cæcum varies in length from two inches to six; the colon is about five feet in length, and the rectum is about eight inches.

The ilium opens into the cæcum, just as the œsophagus opens into the stomach. At this point the ilium is elongated, forming two concentric folds which join at their horns, and between the folds are placed a number of muscular fibres. In this manner is constructed a valve, which is termed the valve of the colon. It is placed in a transverse direction across the intestine, and its action as a valve is very complete. It admits of the free passage of the contents of the small intestines into the large, but it prevents the return of any portion of the contents of the latter into the former.

The colon is distinguished by its capacious size, its great length, and its longitudinal bands, which consist of strong muscular fasciculi (Fig. 92). It is divided into an ascending portion which occupies the right iliac and hypochondriac regions (Fig. 92); the transverse portion, called its arch, which is placed directly across the epigastric region, a descending portion which occupies the left hypochondriac region (Fig. 92), and a fourth portion, which, being curved somewhat like the italic letter *S*, is called the sigmoid flexure, which occupies the left iliac region (Fig. 92). The sigmoid flexure terminates in the last portion of the alimentary canal, called the rectum (Fig. 92), which is placed in the hollow of the sacrum, and which follows the curvature of that bone. The circular fibres of the rectum are accumulated at the termination of the bowel to form the internal sphincter of the anus. External to this is placed another set of fibres, which constitute the external sphincter.

Fig. 93.



Portion of the large intestine, showing the arrangement of the muscular fibres. 1, the longitudinal fibres collected into bands, and forming larger fasciculi; 2, the circular fibres arranged as in the other intestines.

The mucous membrane of the large intestines is disposed differently from that of the small intestines, and the mucous membrane of the colon still differently from that of the rectum. In the colon the mucous membrane, instead of being disposed in the form of valvulæ conniventes, is so arranged as to divide its whole surface into minute apartments or cells, by which the descent of the fecal matter is retarded still more than the descent of the chyle by the valvulæ conniventes. Some particles of chyle do, however, continue to be separated from the fecal matter, even in the large intestines; and in order that nothing may be lost, a few valvulæ conniventes, with their lacteals, appear here also, while the cells of the colon, by retarding the descent of the fecal matter, allow time for the more complete separation and absorption of the chylous particles.

In the rectum the mucous membrane is plaited into large transverse folds, which disappear as the fecal matter descends into the bowel, accumulates in it, and distends it; an arrangement which gives to this portion of the intestine its power of distension, so closely connected with our convenience and comfort.

As soon as that portion of the alimentary matter which is transmitted to the large intestines reaches the colon it ceases to be alkaline, the distinctive character of the contents of the small intestines, and becomes acid, just as the whole alimentary mass is acid at the commencement of digestion in the stomach. It acquires albumen; its gases are no longer the same, for whereas pure hydrogen is contained in the small intestines, none is ever found in the large, but in the place of it, carburetted and sulphuretted hydrogen; and now for the first time it receives its peculiar odour. As it continues to descend, its fluid parts are progressively absorbed, so that it becomes more and more solid, until it reaches the rectum, when it is almost dry. Here the accumulation of it goes on to a considerable extent, the peristaltic action at first excited by the distension of the rectum being, it would appear, counteracted by the contraction of the external sphincter of the anus. When, however, the distension of the bowel reaches a certain point, it produces a sensation which leads to the desire to expel its contents. The bowel is now thrown into action, and that action is powerfully assisted by the descent of the diaphragm and the contraction of the abdominal muscles, actions induced by an effort of the will. Thus the action of the first part of the digestive apparatus, that which is connected with the reception and partly with the deglutition of the food, is attended with consciousness, and is placed under the control of the will; the main portion of the digestive apparatus, that in which the essential part of the digestive process is carried on, is without consciousness, and is placed beyond the influence of volition; the last portion of the digestive apparatus, that connected with the expulsion of the non-nutrient portion of the aliment, again acquires sensibility and consciousness, and is placed under the control of the will. The striking differences in the arrangement of the muscular fibres in these different parts of the apparatus, in accordance with the widely different function performed by them; the powerful muscles connected with the prehension, mastication, and deglutition of the food; the delicate and transparent tissue of fibres forming the muscular coat of the stomach and small intestines; the increase in the number and strength of the fibres of the large intestines, and the prodigious accession to them in the rectum, are adjustments not only exquisite and admirable in their own nature, but so indispensable to our well-being and comfort, that were the appropriate action of either to be suspended but for a short period, life would be extinguished, or if it could be protracted, it would be changed into a state of unbearable torment.

From the preceding account of the structure and action of the apparatus of digestion, on a comparison of all the phenomena, it appears that the successive stages of the process are marked by the progressive approximation of the food to the nature of the blood. The main constituents of the blood are albumen, fibrin, an oily principle, and red particles. Even in the chyme there are traces of albumen. In the chyle of the duodenum the quantity of albumen is larger, there are traces of fibrin, and of an oily matter. In the chyle, after its exit from the mesenteric glands, the oil remains much in the same proportion, the albumen is slightly lessened in amount, whilst there is more fibrin, and a large and increasing number of round globules are found, which much resemble, on the one hand, the corpuscles already spoken of as lining the passages of the mesenteric glands, and, on the other, the white corpuscles of the blood, so that they probably are intermediate stages between these. But in the chyle when it reaches the thoracic duct, these principles are so augmented, concentrated, and approximated to the state in which they exist in the blood, that the chyle is now capable of undergoing the characteristic process of the blood; for as the blood, when drawn from a vein, undergoes spontaneous coagulation, so the chyle, when drawn from the thoracic duct, separates into three parts: a solid substance or clot, which remains at the bottom of the vessel; a fluid which surrounds the clot; and a thin layer of matter, which is spread over the surface of the fluid. The solid substance is analogous to the fibrin, and the fluid to the serum of the blood; while the layer of matter which is spread over the fluid is of an oily nature: moreover, the chyle, when in contact with the air, quickly changes to a red colour, and abounds with minute particles, the largest of which more than equal the size of the red particles of the blood.

The changes wrought upon the food, by which it is thus approximated to the chemical composition of the blood, are effected, as has been shown, partly by the gastric and intestinal juices, and partly by matters combined with the food highly animalised in their own nature, and endowed with assimilative properties, as the salivary secretion mixed with the food during mastication; the pancreatic and biliary secretions mixed with the food during the conversion of the chyme into chyle; and the mesenteric secretions mixed with the elaborated chyle of the mesenteric glands; and, lastly, organised particles which have already formed a part of the living structures of the body mixed with the chyle under the form of lymph in the thoracic duct.

The lymph, until lately regarded as excrementitious, is really highly animalised, partly combined with the chyle as its last and highest assimilative matter; whence the compound formed by the admixture of chyle and lymph is far more proximate to the blood than the purest and most concentrated chyle; and partly returning with the chyle to the lungs, to receive there a second depuration, and thereby a higher elaboration.

There is evidence that there is a series of organs specially provided for the elaboration of the lymph no less than of the chyle. There are organs manifestly connected with the digestive apparatus, to which physiologists have found it extremely difficult to assign a specific office. These organs have a structure in some essential points alike; that structure is strikingly analogous to the organisation of glands: like glands, they receive a prodigious quantity of arterial blood, and are supplied with a proportionate number of organic nerves; yet they are without an excretory duct. The organs in question are the bodies called the renal capsules, placed above the kidneys; the thyroid and thymus glands situated in the neck, and the spleen in close connexion with the stomach.

These organs, however analogous in structure to glands, cannot, it has been argued, be secreting organs, because they are destitute of an excretory duct, do not manifestly form from the blood any peculiar secretion, or, if they do, since there are no means of detecting where it is conveyed, it is impossible to understand how it is appropriated. But if these organs collect, concentrate, and elaborate lymph, preparatory to its admixture with the chyle and to its being sent a second time into the blood to undergo a second process of depuration, they perform the function of glands; and their want of an excretory duct, which has hitherto rendered their office so obscure, is accounted for; they do not need distinct tubes for the transmission of any product of secretion; the lymphatic vessels which proceed from them and which convey the fluid they elaborate into the receptacle of the chyle, are their excretory ducts. That one of these organs, the spleen, is specially connected with the elaboration of the lymph, is manifest, both from its chemical nature and from the remarkable change which takes place in the chyle the moment the lymph from the spleen is mixed with it. Tiedemann and Gmelin state, as the uniform result of their observations and experiments, that the quantity of fibrin contained in the chyle is greatly increased, and that it actually acquires red particles as soon as the lymph from the spleen is mixed with it, and that the lymph from the spleen superabounds both with fibrin and with red particles. That the organs just enumerated, with the spleen, perform a similar function, is inferred from their being, like it, of a glandular structure, and without any excretory duct. If the spleen be really one of a circle of organs appropriated to a function such as is here supposed, a purpose is assigned to it adequate to its rank in the scale of organisation; inferior to few, if its importance be estimated by the quantity of arterial blood with which it is supplied; yet this is the organ for which Paley could find no better use than that of serving for package.

But in whatever mode the lymph be elaborated, it is certain that it consists of matter highly animalised, and that its most important principles, its albumen, its fibrin, its globules, and even its salts, are in a chemical condition closely resembling that in which they exist in the blood.

It will appear hereafter that all the proximate principles of which the body is composed are reducible to three classes, namely, those allied to starch, to oil, and to albumen: of these, starch and oil are the least, and albumen the most highly organised. Every alimentary substance must contain at least one of these proximate principles, and in the various articles which compose an ordinary meal always two, and often all three, are afforded in abundance. From the phenomena which have been stated, it is clear that the digestive organs, in acting on these principles, exert the following powers:—

1. A solvent power. The first action of the stomach on the alimentary substances presented to it is to reduce them to a fluid state. No substance is nutritious which is not a fluid, or capable of being reduced to a fluid. The stomach reduces alimentary substances to a fluid state by combining them with water. Water enters into the composition of organised bodies in two states, as an essential and as an accidental element. A quantity of water is contained in sugar when reduced to its dryest state; this water cannot be dissipated without the decomposition of the sugar; it is therefore an essential constituent of the compound. Water is combined with sugar in its moist state: of this water much may be removed without destroying the essential properties of the sugar: this part of the water is therefore said to be an accidental constituent of the sugar. In most cases organised bodies contain water in both these forms; and though it is commonly impossible to discriminate between the water that is essential and that which is accidental, yet the mode of union among the elements of bodies in these two states of their combination with water are essentially different. The stomach has the power of combining water with alimentary substances in both these forms. Thus fluid albumen, or white of egg, presented to the stomach is immediately coagulated or converted into a solid. Soon this solid begins to be softened, and the softening goes on until it is again reduced to a fluid. What was fluid albumen in the white of egg is now fluid albumen in chyme; but the albumen has undergone a remarkable change. Out of the stomach the albumen of the egg may be converted by heat into a firm solid; but the albumen of the chyme is capable of being converted only into a loose and tender solid. In passing from its state in the egg to its state in the chyme, the albumen has combined with a portion of water which has entered as an essential ingredient into its composition. By this combination the compound is reduced from what may be called a strong to a weak state. This is the first action exerted by the stomach on most alimentary substances. They are changed from a concentrated to a diluted, from a strong to a weak state: the power by which the stomach effects this change is called its reducing power, and the agent by which it accomplishes it is the gastric juice; the essential ingredient of which has been shown to be muriatic acid, or chlorine (p. 218). The muriatic acid obtained from the common salt of the blood is poured in the form of gastric juice into the stomach, dis-

solves the food, combines it with water, reduces it from a concentrated solid to a dilute fluid; and thus brings it into the condition proper for the subsequent part of the process.

2. A converting power. Since whatever be the varieties of food, the chyme invariably forms a homogeneous fluid, the digestive apparatus must be endowed with the power of transforming the simple alimentary principles into one another; the saccharine into the oily, and the oily into the albuminous. The transformation of the saccharine into the oleaginous principle is traceable out of the body in the conversion of sugar into alcohol, which is essentially an oil. That the same transformation takes place within the body is indubitable. The oleaginous and the albuminous principles are already so nearly allied in nature to animal substance that they do not need to undergo any essential change in their composition.

3. A completing power. When the alimentary substances have been reduced and formed into chyme, when the chyme has been converted into chyle, and when the chyle absorbed by the lacteals is transmitted to the mesenteric glands, it undergoes during its passage through these organs a process the direct reverse of that to which it is subjected in the stomach; for whereas it is the office of the stomach to combine the alimentary substances with water, it is one office of the mesenteric glands to remove the superfluous water of the chyle; to abstract whatever particles of matter may be contained in the compound which are not indispensable to it, and to concentrate its essential constituents; and consequently these organs exert on the digested aliment a completing, in contradistinction to a reducing power.

4. A vitalizing power. When sugar is converted into oil, when oil is converted into albumen, when albumen, by the successive processes to which it is subjected is completed, that is, when the alimentary substances are made to approximate in the closest possible degree to the nature of animal substance, they must undergo a still further change. more wonderful than any of the preceding, and far more inscrutable; they must be endowed with vitality; must be changed from dead into living matter. Living substance only is capable of forming a constituent part of living substance. The ultimate action of the digestive organs is the communication of life to the food, to which last and crowning process the reducing, converting, and completing processes are merely subordinate and preparatory. Of the agency by which this process is effected we are wholly ignorant; we know that it goes on; but the mode in which it is accomplished is veiled in inscrutable darkness.

Blood is alive; blood is formed from the food; life is communicated to the food before it is mixed with the blood. The blood is essentially albumen, which it contains in the form of albumen properly so called, in that of fibrin, and in that of red particles. In the thoracic duct the strong albumen of the lymph is mixed with the weaker albumen of the chyle. At the point where the thoracic duct terminates in the venous system, lymph and chyle are mixed with venous blood, and all commingled are borne directly to the lungs. There the carbon with which the venous blood is loaded is expelled in the form of carbonic acid gas; the particles of the lymph undergo some, as yet unknown, change, exalting their organisation; and the water hitherto held in chemical union with the weak albumen of the chyle, is separated and carried out of the system together with the carbonic acid gas in the form of aqueous vapour. By this removal of its aqueous particles the ultimate completion is given to the digested aliment; and the weak and delicate albumen of the chyle is converted into the strong and firm albumen of the blood.

It has been stated, that though gelatin enters abundantly into the composition of many tissues of the body, and performs most important uses in the economy, it is never found in the blood; that it is formed from the albumen of the blood by a reducing process, in consequence of which carbon is evolved, which unites with the free oxygen of the blood, forming carbonic acid, thus conducing, among other purposes, to the production of animal heat. It is equally remarkable, that though the lymphatics or absorbents arise in countless numbers from every tissue of the body, and are endowed with the power of taking up every constituent particle of every organ, solid as well as fluid, yet gelatin is never found in the lymphatic vessels. The lymphatics contain only albumen in a form far more proximate to the blood than that of the chyle; consequently, before the gelatin of the body is taken up by the lymphatics, it must be reconverted into albumen; that is, the absorbed gelatin must undergo a process analogous to that which gelatin and other matters undergo in the stomach and duodenum; it follows that the digestive process is not confined to the stomach and duodenum, but is carried on at every point of the body. Hence there are two processes of digestion, a crude and a refined process. The crude process is carried on in the stomach and duodenum, in which dead animal matter is converted into living substance, as yet, however, possessing only the lowest kind of vitality. The capillary arteries receiving the substance thus prepared for them, build it up into structure perhaps the lowest and coarsest, the least organised, and capable of performing only the inferior functions.

The lymphatic vessels probably take up from the tissues particles already organised, in order to submit them to processes which communicate to them a progressively higher organisation. The notion that the contents of the lymphatics consist of worn-out particles, capable of accomplishing no further purpose in the economy, is not tenable:—

1. Because it is not analogous to the ordinary operations of nature to mix wholly excrementitious matter with a substance for the production, elaboration, and perfection of which, she has constructed such an expensive apparatus.

2. Because, on the other hand, the admixture of matter already highly animalised with matter, as yet but imperfectly animalised, exalts the nature of the latter, and is conducive to its complete animalisation.

3. Because the lymph, almost wholly albuminous, is already closely allied in nature to the blood; it is, therefore, reasonable to infer, that it is matter passing through an advancing stage of purification and exaltation.

4. Because this plan of progressive organisation is in harmony with the ordinary operations of nature, in which there is traceable a successive ascent from the low to the high, the former being preparatory and necessary to the latter. The tender and delicate organs of animal life, the brain, the nerves, the apparatus of sense, the muscles, inasmuch as they perform the highest functions, probably require to be constructed of a more highly organised material, for the production of which the matter primarily derived from crude aliment is subjected to different processes, rising one above the other in delicacy and refinement; by each of which it is made successively more and more perfect, until it acquires the highest qualities of living substance, and is capable of becoming the instrument of performing its most exalted functions.

CHAPTER XV.

OF SECRETION.

Nature of the function—Why involved in obscurity—Basis of the apparatus consists of membrane—Arrangement of membrane into elementary secreting bodies—Cryptæ follicles, cæca and tubuli—Primary combinations of elementary bodies to form compound organs—Relation of the primary secreting organs to the blood-vessels and nerves—Glands, simple and compound—Their structure and office—Development of glands from their simplest form in the lowest animals to their most complex form in the highest animals—Development in the embryo—Number and distribution of the secreting organs—How secreting organs act upon the blood—Degree in which the products of secretion agree with, and differ from, the blood—Modes in which modifications of the secreting apparatus influence the products of secretion—Vital agent by which the function is controlled—Physical agent by which it is effected.

Secretion is the function by which a substance, gaseous, liquid, or solid, is separated or formed from the nutritive fluid. It is a function as necessary to the plant as to the animal, and indispensable alike to the life of both. It is of equal importance to the preservation of the individual and to the perpetuation of the species. In all living beings secretions are separated from the nutritive fluid, and added to the aliment to assist in converting it into nutriment, and are separated from the nutriment to maintain the composition of the nutritive mass in a state fit for the continued performance of the act of nutrition, and to form the germ on the development of which the continuance of the species depends.

The secretions of the plant, varied and abundant, are indispensable to its nourishment, growth, and fructification. The secretions of the animal, more diversified, and far more constantly performed, increase in number and elaborateness in proportion to the range and intensity of the vital endowments and actions. In all animals high in the scale of organisation, and especially in man, the products of secretion are exceedingly complex in nature; some are specially produced, in order to perform a definite purpose in the economy; whilst some substances are separated from the mass, and carried out of the system on account of their uselessness or their noxious properties: all are derived from the nutritive fluid, the blood, and are formed from it by the process of secretion.

In this function are included the most secret and subtle processes of the vital economy,—the ultimate actions of the organic life. Of the real nature of those actions nothing definite is known; and they are modified by agencies over which the art and skill of the experimentalist can exert no adequate control. It is not wonderful therefore that they should be involved in obscurity: nevertheless, when all the phenomena are collected and compared, much of the mysteriousness in which the function appears at first view to be involved vanishes.

The apparatus of secretion is infinitely varied in form: when examined in its complex combinations it appears inextricable in structure, but the diligence and skill of modern research have unfolded much of its mechanism, and enabled us to trace the successive steps by which it passes from its simple to its complex condition.

To form an organ of secretion there must be an artery, a vein, a nerve, an absorbent, and a sufficient quantity of cellular tissue to allow of the free expansion of these vessels and of their complete intercommunication. Membrane constitutes such an organ; for membrane is composed of arteries, veins, nerves, and absorbents sustained and connected by cellular tissue. Hence membrane constitutes a secreting organ, in its simplest form. The most important secreting membranes are the serous, the cutaneous, and the mucous.

Serous membrane, which lines the great cavities of the body, and which gives an external covering to the organs contained in them, forms an extensive secreting surface. Synovial membrane, or that which covers the internal surface of joints, and which constitutes an important portion of the apparatus of locomotion, is essentially the same in structure and office.

Cutaneous membrane, or the skin, which forms the external covering of the body, is an organ in which manifold secretions are constantly elaborated; but the skin is only a modification of the membrane which lines the interior of the body, the mucous. Mucous membrane forms the basis of the secreting apparatus placed in the mouth, fauces, œsophagus, stomach, and intestines in their whole extent; of the secreting apparatus auxiliary to that of the alimentary canal, namely, the pancreas and the liver; probably also of the mesenteric, or lacteal glands, together with the vast system of lymphatic glands, and certainly of the glands of the larynx, trachea, bronchi and air vesicles of the lungs. Hence, while membrane forms the basis of the secreting apparatus in general, mucous membrane is far more extensively employed in its construction than any other form of membrane.

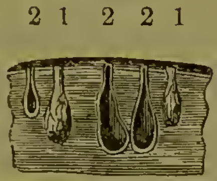
1. In the construction of the secreting apparatus, membrane disposed in the simplest form, constitutes merely a uniform, smooth, extended surface. Serous membrane is always disposed in this simple mode. The costal pleura which lines the internal surface of the walls of the chest; the pulmonary pleura which is continued from the walls of the chest over the lungs; the peritoneum which lines the internal surface of the cavity of the abdomen, and which is reflected over the viscera contained in it; the synovial membrane which covers all the articular surfaces; the arachnoid membrane which envelops the

brain, form simple continuous, serous, secreting surfaces. On the contrary, mucous membrane is never disposed in this perfectly simple mode; even when it forms a continuous surface, as in the lining, which it affords to the alimentary canals, it is more or less plaited into folds or rugæ.

2. The second disposition of membrane in the construction of the secreting apparatus, is the depression of it into a minute pit, called a crypt, which is sometimes rounded to form a cell.

3. Next, the cell, instead of being rounded, is elongated into a peduncle or neck, not unlike the neck of a bottle (Fig. 94). This pedunculated vesicle is called a follicle.

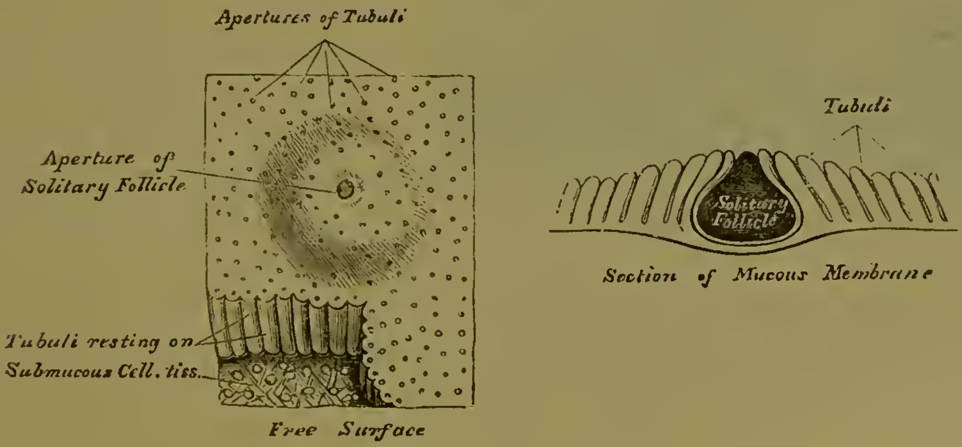
Fig. 94.



Portion of the skin and cellular tissue, showing the sebaceous follicles, as seen under the microscope very highly magnified. 1, the external surface of the follicles with the blood-vessels ramifying upon it; 2, follicles laid open, showing the interior cavity into which the secreted fluid is poured.

4. And, lastly, the pit itself is elongated; so that instead of presenting the appearance of a pouch, it rather resembles a tube (Fig. 95), and is accordingly named tubule.

Fig. 95.


Apertures of Tubuli
Aperture of Solitary Follicle
Tubuli resting on Submucous Cell. tiss.
Free Surface
Tubuli
Solitary Follicle
Section of Mucous Membrane

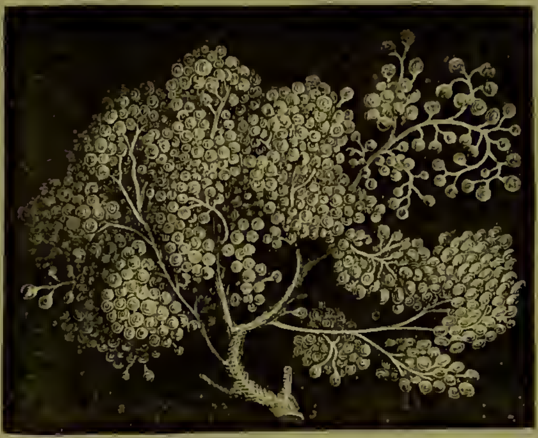
Minute structure of large intestine.

In the construction of the secreting apparatus, membrane, then, may be said to be disposed into three elementary forms constituting cryptæ or cells, follicles, and tubuli. Membrane, disposed into these elementary forms, constitutes the simple bodies by the accumulation and the varied arrangement of which the compound organs are composed. There is no other known element which enters into the composition of the most complex secreting organ.

One of these elementary bodies may exist as a simple organ, or many may be collected into a mass to form a compound organ. When single they are called solitary; when collected into a mass, aggregated. Follicles aggregate by uniting at their orifices, and tubuli by joining and becoming tortuous or convoluted (Fig. 95).

When a single elementary body, as a follicle, forms a distinct secreting organ, the matter secreted is elaborated at the inner surface of the organ, and is contained within its cavity. When needed it quits this cavity at the orifice of the follicle, on the application of the appropriate stimulus. But in the more complex arrangements of these bodies, where the elementary bodies are aggregated into dense, thick masses, when layer after layer of these masses, containing myriads of myriads of follicles or tubuli, are superimposed one upon another, it is impossible that each individual body can have a separate orifice. In this case a minute tube springs from each body; and a complete connexion is established between all the individuals composing the mass by the free intercommunication of these tubes. Of these tubes the minutest unite together, and form larger branches; these larger branches again uniting form still larger branches, until, by their successive union, the branches form at length a single trunk (Fig. 96), with which all the individual branches, whether great or small, communicate, and into which they all pour their contents; the common trunk formed by their union is termed the excretory duct. The secreting canals contain the secreted matter; the excretory duct collects this matter, and conveys it to the part of the body in which it is appropriated to the specific purpose which it serves in the economy.

Fig. 96.



Intimate structure of a composite gland (the parotid); a salivary.

The basis of the secreting canals consists, then, of membrane disposed in one or other of the elementary forms described. These secreting canals constitute a peculiar system of organs wholly different from all the other organs of the body. The form of these organs, their structure and their relation to the blood-vessels and nerves, have formed subjects of laborious investigation and of keen controversy during several centuries. The honour of discovering the exact truth on these points is due to very recent researches.

Professor Müller, of Berlin, has investigated the structure of the secreting apparatus in the whole animal kingdom, and has traced the progressive development of the several secreting organs through the entire animal series, from their simplest form in the lowest animal, to their most complex in the highest.

From the researches of this physiologist, and from the labours of others, his countrymen and contemporaries, who have engaged in the investigation with an ardour second only to his own, it is demonstrated that the secreting apparatus of the animal body is disposed in one or other of the elementary forms which have been described. The blood-vessels are distributed upon the walls of these elementary bodies, whether simple cryptæ, follicles, cæca, or tubuli, or whether these bodies are accumulated and combined into the largest and most complex series of secreting canals, just as the branches of the pulmonary artery are distributed upon the walls of the air-vesicles in the rete mirabile of the lungs. The air-vesicles of the lungs are secreting organs, and afford an excellent example of the mode in which the blood-vessels are distributed upon the walls of the elementary secreting bodies. The arteries do not form continuous tubes with the secreting bodies or their excretory ducts, as was maintained by Ruysh; neither is the secreting body interposed between the termination of the artery and the commencement of the excretory duct, as was thought by Malpighi; but the ultimate divisions of the arteries are spread out upon the walls of the secreting bodies, where they terminate in veins by a delicate vascular net-work. The minutest branch of the artery is always smaller than the minutest secreting body on the walls of which it is distributed. The arteries, spread out upon the walls of the secreting bodies, form a distinct and peculiar system of vessels visible under the microscope. In the more complex secreting organs, they reach their distribution upon the walls of the secreting follicles, and no longer divide and subdivide, but are always of the same uniform size. These ultimate divisions of the arteries are the proper capillaries. It is in these that the changes are wrought upon the blood which it is the object of the various processes of secretion to effect. In the walls of these vessels there are visible no pores, no apertures, no open extremities by which the secreted fluid, when formed from the blood, is conveyed into the cavity of the secreting canals; it probably passes through the walls of the vessels into the secreting canals by the process of endosmose.

Secreting organs are very abundantly supplied with nerves, which are derived for the most part from the organic portion of the nervous system; although for the reasons assigned sentient nerves are mixed with the organic. The more important secreting organs have each a distinct net-work or plexus of organic nerves, which surround the blood-vessels distributed to the organ, and which envelops more especially the arterial trunks and their larger branches. From these plexuses nervous filaments spring in countless numbers, which are spread out upon the walls of the arteries, just as the arteries are spread out upon the walls of the secreting canals. The nerves never quit the arteries; are never spent upon the membranous matter which forms the basis of the secreting organ, but are lost upon the walls of the capillary arteries. The nerves uniformly increase in number and size as the arteries diminish in magnitude and as their capillary terminations become thinner and thinner.

When the secreting apparatus consists of simply extended membrane, a close net-work of capillary arteries with their accompanying nerves is spread out over the whole extent of the secreting surface. This simple arrangement is sufficient to separate from the blood the simple secretion in this case required.

When the secreting apparatus consists of simple follicles, cæca, or tubuli, a similar net-work of capillary arteries and nerves is spread out on the sides of this more extended surface. The more elaborate secretion now formed is received into the interior of these organs, where it remains for some time, and whence it is ultimately conveyed as it is needed by the actions of the system.

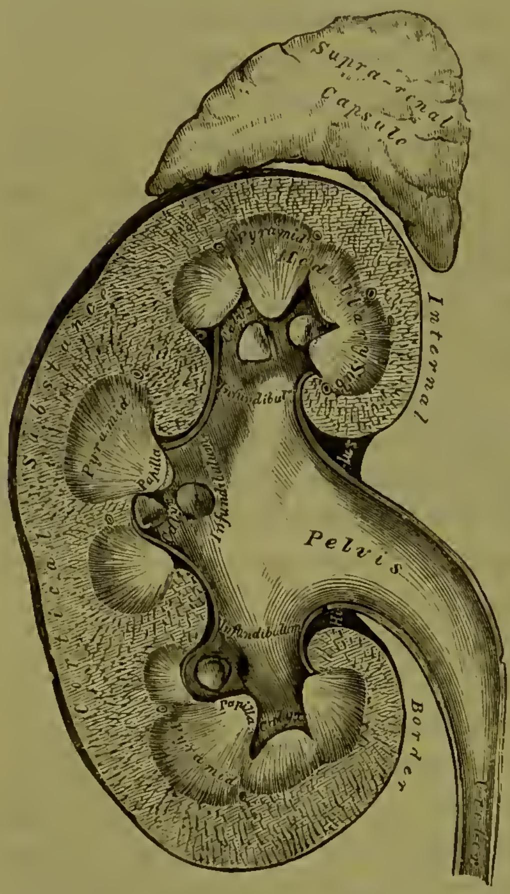
But when the secreting apparatus consists of aggregates of follicles, cæca, and tubuli, with their net-works of arteries and nerves, a much more complex structure is built up, which is destined to perform a proportionably elaborate function. An aggregation of these secreting bodies into a large mass, enveloped in a common membrane, so as to form a distinct body of a solid consistence, constitutes the organ termed a gland. Simply extended membrane, with its apparatus of arteries and nerves, does not constitute a gland. Simple follicles, cæca, and tubuli, with their larger apparatus of arteries and nerves, do not constitute a gland. The first is simply secreting surface; the second are simply secreting cryptæ, follicles, cæca or tubuli; but when these bodies are aggregated into dense and solid masses with an extended system of excretory ducts, and when the whole of this apparatus is enclosed in a proper membrane so as to form a distinct body, such a body is termed a gland.

Thus membrane having a specific arrangement of blood-vessels and nerves, from being simply extended, is folded into a few elementary forms; the bodies which result constitute simple secreting organs; these bodies collected together form, by their aggregation, compound organs; the compound organs, uniting, form aggregates still more compound, until at length a structure is built up highly elaborate and complex. But this complexity of combination and arrangement does not alter the constitution of the organs; their form varies, but their nature remains essentially the same. All consist alike of membrane organised in a similar mode. The complex contains no element not possessed by the simple gland, and the gland contains no element not possessed by the secreting surface. But there is this difference in the complex organs. Every kind and degree of change in the form of the secreting apparatus, from membrane simply extended, to membrane coiled up into the most complex gland, is attended with an accumulation and concentration of secreting surface. The crypt contains a larger extent of secreting surface than the simple membrane; the follicle than the crypt; and the tubulum than the cæcum. A certain amount of secreting surface is gained by the disposition of the simple membrane into the form of the crypt. The collection of a number of crypts into a cluster doubles the extent of the secreting surface by the extent of every crypt that is added to the cluster. The addition of every cluster doubles the whole extent of surface acquired by a single cluster. But when stems spring as if from a common trunk; when branches spring from a stem; when small branches spring from the large branches, and yet smaller branches from the small, in a series which the eye, assisted by the most powerful microscope, is wholly unable to trace; when all the clusters thus formed are collected, and combined into a compact mass, the intricacy of which no art can completely unravel, the extent of surface obtained is altogether immeasurable. How immense must be the extent of surface thus acquired in such an organ as the human lungs, in such a gland as the human liver!

In such an aggregation the concentration is also equal to the accumulation; the maximum of surface is comprised in the minimum of space, and the energy and elaborateness of the function of a secreting organ is uniformly proportionate to such a concentration of its secreting substance.

Hence the complexity of the compound gland in the higher animals would appear to arise solely from the intricate arrangement of the immense mass of secreting matter concentrated in a small compass; hence also the progressively increased complication indicated in the successive development of the glandular system in the animal series. Thus, for example, among the distinct organs formed for the purpose of elaborating a specific secretion, being intimately connected with the process of digestion, one of the first is the salivary gland. Low down in the scale, in the animal in which the first rudiment of a salivary gland is traceable, it consists of a single follicle, which appears to serve the office of a gland. In an animal a little higher in structure, two, three, or four follicles combine to form a somewhat less simple organ. In an animal still higher in the series, a number of follicles are clustered together and form a much more complex organ; and in this manner, as the organisation of the animal becomes higher and higher, the complexity of the gland increases, until at length it is composed of a countless number of follicles collected into clusters, the clusters disposed into lobes, the lobes subdivided into lobules, and the lobules into still smaller particles, the ultimate elements of the glandular apparatus. In like manner, when the first rudiment of the liver is discoverable, it consists of a single pouch or cæcum; somewhat higher in the series, the organ is composed of two or more cæca, distinct and free; and then, as its complexity increases with the perfection of the organisation, cæca are accumulated upon cæca; the aggregates so formed are closely compacted, disposed into lobes, divided into lobules, and subdivided into the ultimate particles of the glandular apparatus. So in a gland composed of tubuli, as the kidney, the organ in its rudimentary state consists of a few straight tubuli (Fig. 97): as its structure advances more tubuli are added: next, the increasing tubuli superimposed one upon another become tortuous; then the tubuli still accumulating, become not merely tortuous, but convoluted; and last of all, countless numbers of tubuli are closely compacted into exceedingly convoluted masses (Fig. 97). Uniformly, the lower the animal and the simpler the organ, the larger and the more manifest are the elementary parts of the gland; but in the higher animals these elementary bodies are so minute as to be altogether microscopical, and their arrangement is so complex that it can be unravelled only with extreme difficulty.

Fig. 97.



Vertical section of kidney.

It is a striking confirmation of the correctness of this view of the structure of the glandular apparatus, that whenever in the ascending series a gland appears for the first time in any class, the elementary bodies are so large, and are disposed in so simple a mode, that a slight examination is sufficient to demonstrate their primitive form, and to render it manifest that they consist either of vesicles, follicles, cæca, or tubuli, more or less aggregated. This is seen in the obvious structure presented by the liver, the pancreas, the salivary glands, and the mammæ, in the simple animals in which these organs first appear. Thus the liver in animals low down in the scale is manifestly composed of simple clustering follicles: in the fish the pancreas is composed of simple branched follicles: in the bird, the salivary glands are composed of simple parallel tubuli; and in the cetacea the breasts are composed of simple branched tubuli.

But the microscope, by bringing the successive development of the compound gland in the embryo of the higher animal under the cognizance of sense, perfectly discloses the nature of its composition. In the development of the incubated egg every step of the progressive formation of the compound gland is rendered visible to the eye. When this process is carefully watched, it is seen that the part of the gland first formed is the excretory duct, which springs from the blastema, the common mass of matter out of which all the organs are formed. From this duct the elementary parts of the gland bud just as bunches of grapes bud from the stalk. The buds, at first at considerable distances from each other, approach nearer as they increase by new growths, until at length they come into actual contact. The growth continuing, and the compactness of the substance of the gland proportionally increasing, the primitive form of the elementary bodies which compose it is ultimately lost. The substance of the gland now appears to consist of compact solid matter, which is commonly termed parenchyma. The component particles of this parenchymatous and apparently solid substance present a clustered or grape-like appearance, from which they early obtained the name of acini, from the Latin word acinus, a berry.

In its embryo state the compound gland of the highest animal consists of mere excretory ducts, wonderfully similar to the simple secreting bodies of the lowest classes. But in the higher animal this simple form of the gland is transient: gradually, with the progressive evolution of the embryo, it passes into a more complex structure; while in the lower animal the simple form of the gland remains permanently the same through the whole term of life.

Such are the main points which have been ascertained relative to the structure of the secreting apparatus, which enters in one or other of its forms, as a constituent element, into almost every part of the animal body. How immense the number of these organs in the human body! Every point in the interior of the walls that bound the great cavities is a secreting surface. Every point of the secreting surface that lines the alimentary canal, from its commencement to its termination, is studded with distinct secreting organs. Every point of the skin is still more thickly studded with distinct secreting organs. By the naked eye, and still more distinctly with a lens, may be seen the pores through which the vapour that constitutes the insensible perspiration incessantly exudes. Next are the open mouths of myriads of sebaceous follicles that pour out upon the skin the oily matter which gives it its suppleness and softness; and besides all these, are the hairs, each the product of a secreting organ placed immediately beneath the skin. An attempt to count the number of pores and hairs visible to the eye within the compass of an inch, and thence to compute the number on the whole surface of the skin, may convey some conception of the amount of these organs; yet these form but a small part of the secreting apparatus. The great viscera of the body, the lungs, the liver, the pancreas, are portions of it; all the organs of the senses, the eyes, the ears, the nose, the tongue; all the organs of locomotion; every point of the surface of every muscle, and a great part of the surface and substance of the very bones are crowded with secreting organs.

How do these organs act upon the blood?

All that is known of the course of that portion of the blood which flows through an organ of secretion is, that it passes into arteries of extreme minuteness, which are spread out upon the external walls of the elementary secreting bodies, and which pass into capillary veins—nowhere terminating by open mouths—nowhere presenting visible outlets or pores; their contents probably transuding through their thin and tender coats by the process of endosmose.

As it is flowing through these capillary arteries, the blood undergoes the transformations effected by secretion, forming—1. The fluids, which are added to the aliment, and which accomplish its solution, and change it into chyme. 2. The fluids, which are added to the chyme to convert it into chyle, and both to chyle and lymph, to assist in their assimilation. 3. The fluids which, poured into the cavities, facilitate the movements of their contents. 4. The fluids which, deposited at different points of the cellular tissue, when more aliment is received than is needed, serve as reservoirs of nutriment to be absorbed when more aliment is required than can be afforded by the digestive organs. 5. The fluids which are eliminated from the common mass, whether of fluids or solids, to be carried out of the system as excrementitious substances. 6. In addition to all these substances, which are indispensable to the preservation of the individual, those which are necessary to the perpetuation of the species.

In order to form any conception of the mode in which the secreting organs act upon the blood, so as to elaborate from it such diversified substances, it is necessary to consider the chemical composition of the different products of secretion, and the degrees in which they really differ from each other, and from the common mass of blood out of which they are eliminated.

By chemical analysis, it is established that all the substances which are formed from the blood by the process of secretion are either water, albumen, mucus, oil, resin, or salts.

In by far the greater number of cases the various substances of which the body is composed are simply separated from the nutritive fluid at the parts of the body at which they are deposited; so that, existing already formed in the blood, they are merely deposited there, and not generated. Still, however, since it is certain that gelatin cannot be recognized in the blood, and since it is doubtful whether some other substances found in different textures and secretions really exist in the blood, it is necessary, in the present state of our knowledge, to suppose, that although most of the constituents of the living tissues are contained in the blood, yet that in some instances a material change is effected in their nature at the time and place of their escape from the circulation; and that in these cases the secreted substances are not simple extracts from, but products of, the blood.

It is by the apparatus of secretion that this separation, evolution, or reformation is effected. Out of a fluid which contains, blended together, almost all the heterogeneous substances of which the body is built up, particular substances are selected from the common mass, and are deposited in certain parts, and only in certain parts. Although by the most careful examination of the structure of the apparatus, it is not possible to form a precise conception of the mode in which this separation is effected, yet we are enabled to perceive a number of arrangements which we can readily understand must conduce to the accomplishment of the object.

1. Of these, the most obvious is mechanical arrangement.

In its passage to different organs the blood is propelled through canals of extreme minuteness: in every different case these canals differ from each other in size; pass off from their respective trunks at different angles; possess different degrees of density; are variously contorted, and are of various lengths. In some they are straight, in others convoluted; at one time branching, at another pencillated, and at another starry. The veins, too, in some cases, are almost straight, in others exceedingly tortuous, in others reticulated; and the freedom of their communication with the arteries varies so much, that in some cases fine injections pass from the one set of vessels to the other with the greatest facility, while, in others, they pass with extreme difficulty. The consequence of these divers arrangements of the capillary blood-vessels is, that the current of the blood must necessarily flow in them with different degrees of velocity; its particles must be placed at different distances from each other, and must be presented to each other in different positions and in widely different proportions. In no two secreting organs are any two of these conditions exactly alike. In the lower orders of animals, in which secretion is seen in its simplest condition, the general nutritive fluid, elaborated and contained in a single internal cavity, appears to furnish a variety of products very different from itself, by a process hardly more complex than mere transudation through a living membrane. In the higher animals the different secreting organs may be considered, in part at least, as mechanical contrivances adapted to carry on analogous transudations—fine sieves or strainers diversly constructed. A fluid containing such heterogeneous matters as the blood, held in combination by so slight an affinity, slowly transuding through series of tubes, the mechanical arrangement of which is so varied, must yield a different substance in every different case. Thus by simply filtering the blood a vast variety of products may be obtained, merely in consequence of a varied disposition of the minute tubes of which the filters are composed.

2. But in the second place, this diversity of mechanical arrangement is calculated in a high degree to promote and to modify chemical action. The contact or proximity of the particles of bodies, the extent of surface which those particles present to each other, the space of time in which they continue in contact, the degree of force with which they impinge against each other, the degree of temperature to which they are exposed,—these, and circumstances such as these, are conditions which exert the most powerful influence over chemical decomposition and recombination. In the different secreting organs, as has been shown, the blood must necessarily pass through vessels having every conceivable diversity of diameter: in those vessels it must consequently flow with corresponding differences of velocity. Some of these diameters will admit one constituent of the blood, as one of the red particles; others may be large enough to admit two or more of the red particles abreast; in some vessels these different constituents will be in one degree of proximity, in others in another; in some they will remain long in contact, in others only for an instant: it is obvious that from such different conditions the chemical products may be infinitely varied.

Such is the composition of chemical bodies, that a great diversity of substance is obtainable merely by changing one condition, the proportions in which the elementary particles combine.

Oxygen and nitrogen combined in one proportion form atmospheric air; in another proportion, nitrous oxide; in another, nitric oxide; in a fourth, nitrous acid; and in a fifth, nitric acid. Few secretions formed from the blood differ more widely from each other than the products thus formed from these two elementary bodies.

Urea consists of two prime equivalents of hydrogen, one of carbon, one of oxygen, and one of nitrogen. Remove one of the atoms of hydrogen, and take away the atom of nitrogen, urea is converted into sugar; combine with urea an additional atom of carbon, it is changed into lithic acid. In like manner, add a small quantity of water to farina, it is converted into sugar; to fibrin, it is changed into adipocere.

From a reservoir containing a quantity of substances in the state of vinous fermentation, draw off portions of the liquor at different stages of the process, and cause these to pass through tubes of various diameters and with various degrees of velocity, there will be obtained at one time an unfermented syrup, at another, a fermenting fluid, at another, wine, at another, vinegar. Out of the body place the blood in a state of rest, it will spontaneously separate into serum and crassamentum, and the crassamentum will further separate into fibrin and red particles. Add to the serum a certain portion of acid, it will be coagulated into solid albumen; add to this solid albumen another portion of acid, it will be converted into jelly. Add a certain portion of acid to fibrin, it will be changed into adipose matter; bring the acid into contact with the red particles, they will be converted into a substance closely resembling bile. If by the rough chemistry which the art of man can conduct so great a variety of substances may be obtained out of a single compound, it is not wonderful that a far greater variety should be produced by the delicate and subtle chemistry of life.

3. But a third most important agent in the process of secretion is some influence derived from the nervous system.

1. It is proved, by direct experiment, that the destruction of the nervous apparatus, or of any considerable portion of it, stops the process of secretion. By experiments performed by Sir B. Brodie, it is ascertained that the secretion of the urine is suspended by the removal or destruction of the brain, though the circulation be maintained in its full vigour by artificial respiration.

2. The section, and still more the removal, of a portion of the sentient nerves of the stomach (the par vagum, or eighth pair), according to some experimentalists, deranges and impedes; according to others, totally arrests the process of digestion.

3. Other classes of phenomena illustrate in a striking manner the influence of the nervous system over the process of secretion. The sight, nay, even the thought of agreeable food, increases the secretions of the mouth. Pleasurable ideas excite, painful ideas destroy, the appetite for food; probably, in the one case, by increasing, and, in the other, by suspending the secretion of the gastric juice: the emotion of grief instantly causes a flow of tears; the sight or thought of her child fills the maternal breasts with milk, while the removal of the child from the mother diminishes and ultimately stops the secretion.

It is probable that the vital agent by which the effect is produced on the secreting organs is the organic nerve. Though the sentient part of the nervous system may in many cases be the part primarily acted on, yet there is reason to believe that the ultimate effect is invariably produced on the organic part, the sentient nerves in this case acting on the organic, as in other cases the organic act on the sentient, in consequence of that intimate connexion which, for the reason assigned, is established between both parts of this system. For,

1. The true object of the sentient part of the nervous system is to establish a relation between the body and the external world; the object of the organic part is to preside over the functions by which the body is sustained and nourished, that is, over the processes of secretion.

2. The nerves which are distributed to the secreting arteries are, for the most part, derived from the organic portion of the nervous system (Fig. 89, 3). This anatomical arrangement clearly points to some physiological purpose, and indicates the closeness of the relation between the function of the organic nerve and the ultimate action of the capillary artery.

The existence of the organic nerve is probably simultaneous with that of the secreting artery: from the first to the last moment of life the nerve regulates the artery; the influence of the one is indispensable to the operation of the other; and, by their conjoint action, the sentient nerve itself, as well as every other organ, is constructed.

There is reason to believe that the physical agent by which the organic nerve influences secretion is allied to electricity. The nerve appears to be the medium by which electrical fluid is conveyed to the secreting organs, and the nerve probably influences secretion by influencing chemical combination, through the intervention of this most powerful chemical agent. This is rendered probable by the observation of various phenomena, and by the result of direct experiment.

1. It is proved that galvanic phenomena may be excited by the contact of the nerve and muscle in an animal recently dead. A galvanic pile may be constructed of alternate layers of nervous and muscular substance, or of nervous substance and other animal tissues. A secreting organ liberally supplied with organic nerve is probably then in its physical structure a galvanic apparatus. It is certain that some animals, as the raia torpedo, possess a special electrical apparatus composed essentially of nervous matter; that the nerves which compose this apparatus correspond strictly with the organic nerves of the human body; that they are distributed principally to the organs of digestion and secretion, and that they exert a powerful influence over these processes; for, when the animal is frequently excited to give shocks, digestion appears to be completely arrested; so that, after the animal's death, food swallowed some time previously is found wholly unchanged.

2. It is universally admitted that the nerves in all animals possess an extreme sensibility to the stimulus of electricity, and more especially to that form of it which is termed galvanism.

3. Direct experiment proves that the stimulus of galvanism may be made to produce in the living body precisely the same effect as the nervous influence. It has been stated, that the division of the par vagum, in the neck of a living animal, suspends the digestion of the food probably by stopping indirectly the secretion of the gastric juice. If after the division of the nerves, their lower ends, that is, that portion of the nerves which is still in communication with the stomach, but no longer in communication with the brain, be made to conduct galvanic fluid to the stomach, secretion goes on as fast as when the nerves are entire and conduct nervous influence. Dr. Wilson Philip having divided the par vagum in the neck of a living animal, coated a portion of the lower end of the nerves with tin foil, placed a silver plate over the stomach of the animal, and connected respectively the tin and silver with the opposite extremities of a galvanic apparatus. The result was that the animal remained entirely free from the distressing symptoms which had always before attended the division of the nerves, and that the process of digestion, which had been invariably suspended by this operation, now went on just as in the natural state of the stomach. On examining the stomach after death, the food was found perfectly digested, and afforded a striking contrast to the state of the food contained in the stomach of a similar animal, in whom the nerves had been divided, but which had not been subjected to the galvanic influence.

4. On applying a low galvanic power to a saline solution contained in an organic membrane, Dr. Wollaston found that the galvanic fluid decomposed the saline solution, and that the component parts of the solution transuded through the membrane; each constituent being separately attracted to the corresponding wire of the interrupted circuit. This experiment, says this acute and philosophical physiologist, illustrates in a very striking manner the agency of galvanism on the animal fluids. Thus the quality of the secreted fluid may probably enable us to judge of the electrical state of the organ which produces it; as for example, the general redundance of acid in urine, though secreted from blood that is known to be alkaline, appears to indicate in the kidney a state of positive electricity; and since the proportion of alkali in bile seems to be greater than is contained in the blood of the same animal, it is not improbable that the secretory vessels in the liver may be comparatively negative.

Considerations such as these afford us a glimpse into the mode in which Nature conducts some of her most secret and subtle operations; or rather into the immediate agency by which she effects them; for, properly speaking, of the mode in which she works; we do not obtain the slightest insight, and even of her immediate agency our view, at least in the present state of our knowledge, is indistinct and vague. By the study of the apparatus which she builds up, we can trace back her operations a step or two; but in every case, at a certain point, the apparatus itself becomes so delicate as to elude our senses, and then of course we are necessarily at a stand. So, the rough materials with which she carries on her great work of secretion, by careful analysis we can separate into divers parts, and ascertain that each part possesses peculiar properties. The main channels by which she conveys these varied constituents to the different parts of the system we can trace; the delicate organs by which she produces on these rude materials her wonderful transformations we can see; but beyond the threshold of these organs we cannot go. Why from one common mass of fluid the same variety of peculiar substances are constantly separated, and each in its respective place: why the kidney never secretes milk, nor the liver urine, nor the breast bile: why membrane, and muscle, and bone, and fat, and brain, are uniformly deposited in the same precise situation: why these depositions go on with uniformity, constancy and regularity; and by what laws each process is controlled and modified, we do not know. But though with whatever diligence we investigate these operations, the great problem remains, and probably ever will remain unresolved, still it is both a pleasurable and a profitable labour to follow Nature in her path, to the extreme point to which it is possible to trace her footstep; for the phenomena themselves are often in the highest degree curious and interesting; while their order and relation can seldom be so considered as to be understood, without the suggestion of practical applications of great and permanent usefulness.

CHAPTER XVI.

OF THE FUNCTION OF ABSORPTION.

Evidence of the process in the plant, in the animal—Apparatus general and special—Experiments which prove the absorbing power of blood-vessels and membrane—Decomposing and analysing properties of membrane—Endosmose and exosmose—Absorbing surfaces, pulmonary, digestive, and cutaneous—Lacteal and lymphatic vessels—Absorbent glands—Motion of the fluid in the special absorbent vessels—Discovery of the lacteals and lymphatics—Specific office performed by the several parts of the apparatus of absorption—Condition of the system on which the activity of the process depends—Uses of the function.

Absorption is the function by which external substances are received into the body, and the component particles of the body are taken up from one part of the system, and deposited in some other part. So universal and constant is the operation, that there is not a fluid nor a solid, not a surface nor a tissue, not an external nor an internal organ, which is not, in its turn, the seat and the subject of the process. By its action the component particles of the living body are kept in a state of perpetual mutation.

If a quantity of water be injected into any of the great cavities of the body, as into that of the peritoneum, the whole of the fluid after a certain time disappears; it is spontaneously removed.

If in the progress of disease a fluid be poured into any cavity of the body, as often happens in dropsy, the whole of the fluid is removed, sometimes spontaneously and quite suddenly; but more often slowly, under the influence of medicinal agents.

Certain substances, whether applied to an external or an internal surface, produce specific effects on the system, just as when they are received into the stomach or injected into the blood-vessels. Mercury in mere contact with the skin, but more rapidly when the application is aided by friction, produces the same specific action upon the salivary glands, and the same general action upon the system as when the preparation of the metal is received into the stomach. By the like external and local application arsenic, opium, tobacco, and other narcotics produce their distinct and peculiar effects on the nervous system, and their remote and general effects on the other systems.

If an organ or tissue be deprived of nourishment, it gradually diminishes in bulk, and at length wholly disappears from the system. By long-continued pressure, such as that occasioned by the pulsation of a diseased artery, as in aneurism, or by the growth of a fleshy tumor, portions of the firmest and strongest muscle, nay, even of the most dense and compact bone, wholly disappear. At one time the fluids diminish in quantity, the flesh wastes, and the weight of the body is reduced one half or more. Under other circumstances, while the state of the general system remains stationary, some particular part diminishes in size, or altogether disappears.

Healthy and strong men, engaged in hard labour and exposed to intense heat, sometimes lose, in the space of a single hour, upwards of five pounds of their weight. Though daily engaged for months together in this occupation at two different periods of the day, for the space of an hour each time, and though consequently these men lose five pounds twice every day, yet when weighed at intervals of three, six, or nine months, it is found that the weight of the body remains stationary, not varying, perhaps, more than a pound or two. It follows that the bodies of these men must absorb, twice every day, a quantity equal in weight to that which they lose.

These phenomena depend on a power inherent in the body, that of taking up and carrying into the system certain substances in contact with its surfaces, and of transporting from one part of its system to another its own component particles.

The apparatus by which these operations are carried on is general and special.

The general apparatus consists of blood-vessels and membrane. The special apparatus consists of a peculiar system of vessels, namely, the lacteals and lymphatics, together with the system of glands termed conglobate.

It is proved by direct experiment that the walls of blood-vessels exert a power by which substances in contact with their external surface penetrate their tissue, reach their internal surface, and mix with the mass of the circulating fluids, and that this property is possessed by all blood-vessels, arteries and veins, great and small, dead and living.

If a portion of a vein or artery taken from the body be attached by either extremity to two glass tubes in order to establish a current of warm water in its interior, if the vein be then placed in a fluid slightly acidulated, and the fluid which flows through the vessel be collected in a flask, this latter fluid becomes, in the space of a few minutes, sensibly acid. In this experiment there is no possibility of communication between the current of warm water and the external acidulated fluid, consequently the latter must penetrate the parietes of the vessel, that is, absorption must take place through its membranous walls.

A striking experiment demonstrates the absorbing power of the living blood-vessels. If the trunk of a vein or artery be exposed in a living animal, and a poisonous substance in solution be dropped on the external surface of either, the animal is killed in a few minutes, just as when the poison is injected into the blood-vessel itself. Analogous experiments on the minute blood-vessels not only show that they are endowed with the like absorbing power, but that their number, tenuity and extent, are conditions which greatly favour the activity of the process.

Membrane is an organised substance abounding with blood-vessels. Whether the absorbing power possessed by this tissue be due only to these vessels, or whether it be assisted in the operation by other agents not yet fully ascertained, it is certain that the absorbing power it exerts is highly curious and wonderful.

An animal membrane placed in contact with water becomes saturated with fluid: placed in contact with a compound fluid, as with water or spirit holding colouring matter in solution, the membrane actually decomposes the compound and resolves it into its elementary parts, just as accurately as can be done by the chemist. If one extremity of a piece of membrane be placed in a vessel containing the tincture of iodine, for example, and the other extremity be kept out of the fluid, that portion of the membrane which is in immediate contact with the tincture acquires a perfectly dark colour, because the iodine completely penetrates the substance of the membrane. This dark-coloured portion is bounded by a definite line, above which the membrane is penetrated by a different part of the solution, by a pearly colourless fluid, the alcohol in which the iodine was suspended. Above this again there are traces of a still lighter coloured fluid, which is probably water. In like manner, if strips of membrane are placed in glasses containing port wine, the same analytical process is effected by the membrane. The colouring matter of the wine is imbibed by the lower portion of the membrane; above this is the alcohol, and above this the water.

These and many analogous experiments demonstrate that the process of absorption is accompanied with the further phenomena of decomposition and analysis; and that membrane, at the very moment it imbibes certain compound substances, resolves them into their constituent elements.

It is further established by numerous experiments that different compound substances are decomposed and absorbed by membrane with different degrees of facility. If strips of membrane are placed in phials containing different kinds of fluids, one fluid rises only a line or two; others rise to the height of many inches. There is indubitable evidence that analogous properties are possessed by living membrane; that the mucous membrane of the stomach at the moment it imbibes, decomposes and analyses the alimentary and medicinal substances in contact with its surface; and consequently that in all animals membrane becomes a most important agent in carrying on the digestive process.

But perhaps the most remarkable property possessed by membrane is that of establishing in fluids in contact with its surfaces currents through its parietes, which proceed in opposite directions, according to the different natures of the fluids, and more especially according to their different densities. If small bladders composed of membrane are filled with a fluid of greater density than water, and securely fastened, and then thrown into water, they acquire weight and become swollen and tense. If the experiment be reversed; if the bladders be filled with water and immersed in a denser fluid, the denser fluid flows inwards to the water, and the water passes from the interior outwards. M. Dutrochet, who was led by accident to the observation of these phenomena, and who saw at once the possible importance of this agency in some organic processes hitherto involved in great obscurity, commenced an extended series of experiments with a view to ascertain the exact facts. He took the cæca of fowls, membranous bags already made to his hand, into which he introduced a quantity of fluid consisting of milk, thin syrup, or gum-arabic dissolved in water. Having securely tied the membranes, he placed the bags thus filled in water, and found that two opposite currents are established through the walls of the cæca. The first and strongest current, that from without inwards, is formed by the flow of the external water towards the thicker fluid contained in the cæca; the second and weaker current, that from within outwards, is formed by the flow of the thicker interior fluid towards the external water. The first or the in-going current is termed *endosmose,* from ενδον, intus, and ωσμος, impulsus, and the second or out-going current is termed *exosmose,* from a similar combination of Greek words signifying an impulse outwards.

The velocity and strength of these currents are capable of exact admeasurement. The amount of endosmose is measured by an apparatus termed an endosmometer, which consists of a small bottle, the bottom of which is taken out and the aperture closed by a piece of bladder. Into this bottle is poured some dense fluid; the neck of the bottle is closed with a cork, through which a glass tube, fixed upon a graduated scale, is passed. The bottle is then placed in pure water. The water by endosmose penetrates the bottle in various quantities according to the density of the fluid contained in its interior through the membrane closing its bottom. The dense fluid in the bottle, increased in quantity by the addition of the water, rises in the tube fitted to its neck, and the velocity of its ascent is the measure of the velocity of the endosmose.

The strength of endosmose is measured by a similar apparatus, in which a tube is twice bent upon itself, and the ascending branch containing a column of mercury which is raised by the fluid in the interior of the endosmometer, as the volume of this fluid is increased by the endosmose. By means of these two instruments it is found that the velocity and strength of endosmose follow the same law, and that both are proportionate to the excess of the density of the fluid contained in the endosmometer above the density of water. By numerous experiments it is ascertained that by employing syrup of ordinary density an endosmose is obtained, the strength of which is capable of raising water more than 150 feet.

But though difference of density is necessary to the production of endosmose, yet numerous and decisive experiments show that the different natures of fluids, irrespective of their proportionate densities, materially influence the activity and energy of the process. Thus, if sugar-water and gum-water of the same density be placed in the same endosmometer, the former produces endosmose with a velocity as seventeen and the latter only as eight. The endosmose produced by a solution of the sulphate of soda is double that produced by a solution of the hydro-chlorate of soda of the same density. A solution of albumen exerts an endosmose four times greater than a solution of gelatin of the same density.

With organic fluids endosmose goes on without ceasing until the chemical nature of the fluids becomes altered by putrefaction; but with alkalies, soluble salts, acids, and chemical agents in general, the endosmose excited is capable only of short continuance, because such agents enter into chemical combination with the organic tissue of the endosmometer, and thus destroy endosmose.

It is remarkable that the direction of the endosmotic currents produced by vegetable membrane is the exact reverse of that produced by animal membrane under precisely the same circumstances. Thus oxalic acid, when separated from water by an animal membrane, invariably exhibits endosmose from the acid towards the water; when separated by a vegetable membrane, from the water towards the acid: and the same is the case with the tartaric and citric acids, and with the sulphuric, the hydro-sulphuric, and the sulphurous acids. I filled, says Dutrochet, a pod of the *colutea arborescens* (which being opened at one end only, and forming a little bag, was readily attached by means of a ligature to a glass tube) with a solution of oxalic acid, and having plunged it into rain-water, endosmose was manifested by the ascent of the contained acid fluid in the tube, that is to say, the current flowed from the water towards the acid. The lower part of the leek (*allium porrum*) is enveloped or sheathed by the tubular petioles of the leaves. By slitting these cylindrical tubes down one side, vegetable membranous webs of sufficient breadth and strength to be tied upon the reservoir of an endosmometer are readily obtained. An endosmometer, fitted with one of these vegetable membranes, having been filled with a solution of oxalic acid and then plunged into rain-water, the included fluid rose gradually in the tube of the endosmometer, so that the endosmose was from the water towards the acid, the reverse of that which takes place when the endosmometer is furnished with an animal membrane. Vegetable membrane, then, at least with fluids containing a preponderance of acid, produces a current, the direction of which is the exact reverse of that produced by animal membrane.

The bodies of organised beings are composed in great part of various fluids of different density, separated from each other by thin septa, precisely the conditions which are necessary to the production of endosmose. But such conditions never concur in inorganic bodies, whence inorganic bodies never exhibit endosmotic phenomena. Vegetable tissue of every kind consists of vast multitudes of aggregated cells intermingled with tubes. The parietes of these hollow organs are exceedingly delicate and thin; the organs themselves are at all times filled with fluids, the densities of which are infinitely various; consequently, by endosmose and exosmose, mutual interchanges of their contents incessantly go on; those contents brought into contact by currents moving now in one direction and now in another, now rapidly and now slowly, intermingle, and in consequence of their admixture, changes in their chemical composition take place. It is by these powers that water holding in solution nutrient matter diffused through the soil penetrates the spongeolæ of the capillary rootlets, always filled with a denser fluid than the water contained in the soil, —that the energetic motion by which the sap ascends is generated,—that the ascending sap is attracted into fruits, always of greater density than the crude sap,—that buds are capable of emptying the tissue that surrounds them when they begin to grow, and that almost all the phenomena connected with the motions of fluids in plants, and the chemical changes which those fluids undergo in consequence of this admixture, is effected. And there cannot be a question that analogous phenomena take place in the various cells, cavities, and minute capillary vessels of the animal body.

It is then established on indubitable evidence that all animal tissues, without exception, possess an inherent property by which they are capable of transmitting through their substance certain fluids, and even solids, convertible into fluids; and that the great agent by which this transmission is effected is membranous tissue, whether in the form of blood-vessels or of proper membrane. By virtue of this property fluids and solids are absorbed, by the animal body, with whatever surface or organ they are in contact, whether with an external or an internal surface, or with the eye, the mouth, the tongue, the stomach, the lungs, the liver, or the heart.

But membrane is so disposed and modified, in different parts of the body, as to admit of the introduction of fluids and solids from the exterior to the interior of the system with widely different degrees of facility. There may be said to be in the human body three great absorbing surfaces, the pulmonary, the digestive, and the cutaneous, each highly important, but each endowed with exceedingly different degrees of absorbing power.

The pulmonary surface, for reasons which will be readily understood from what has been already stated relative to the structure of the air-vesicles of the lungs, is by far the most active absorbing surface of the body. The mode in which the air-vesicles are formed and disposed has been shown to be such as to give to the lungs an almost incredible extent of membranous surface, while the membrane of which the cells are composed is exceedingly fine and delicate. Moreover, there is the freest possible communication between all the branches of the pulmonary vascular system, whether arteries or veins; the distance between the lungs and the heart is short; the course of the blood from the pulmonary capillaries to the central engine that works the circulation is rapid, and the lungs are at the same time close to the central masses of the nervous system, with which indeed they are placed in direct communication by nerves of great magnitude and of most extensive distribution. These circumstances account for the wonderful rapidity with which substances are absorbed, when placed in contact with the pulmonary surface, and for the instantaneousness and intensity of the impression produced upon the system, when the substance thus introduced is of a deleterious nature.

They also afford an explanation of a phenomenon not to have been credited without experience of the fact, that innoxious substances introduced into the air-cells of the lungs in moderate quantities produce no more inconvenience there than when taken into the stomach. A single drop of pure water, when in contact near the glottis with the same membrane that forms the air-vesicles of the lungs, excites the most violent and spasmodic cough, and the smallest particle of a solid substance permanently remaining there occasions so much irritation that inevitable suffocation and death result. Yet so different is the sensibility of this membrane in different parts of its course, that while at the upper portion of the trachea it will not bear a drop of water without exciting violent disturbance, in the air-vesicles it tolerates with only slight inconvenience a considerable quantity even of solid matter. An accident of a nature sufficiently alarming, which occurred to Dessault, affords a striking illustration of this curious fact. This celebrated surgeon had to treat a case in which the trachea and œsophagus were cut through. It was necessary to introduce a tube through the divided œsophagus into the stomach, and to sustain the patient by food introduced in this manner. On one occasion the tube, instead of being passed through the œsophagus to the stomach, was introduced into the trachea down to the division of the bronchi. Several injections of soup were actually thrown into the lungs before the mistake was discovered; yet no fatal, and even no dangerous consequences ensued. Since that period, in various experiments on animals, several substances of an innoxious nature have been thrown into the lungs without producing any inconvenience beyond slight disturbance of the respiration and cough. The reason is, that after a short time the substances are absorbed by the membrane composing the air-vesicles, and are thus removed from the lungs and borne into the general circulating mass. At every point of the pulmonary tissue there is a vascular tube ready to receive any substance imbibed by it, and to carry it at once into the general current of the circulation.

Hence the instantaneousness and the dreadful energy with which poisons and other noxious substances act upon the system when brought into contact with the pulmonary tissue. A solution of nux vomica injected into the trachea produces death in a few seconds. A single inspiration of the concentrated prussic acid kills with the rapidity of a stroke of lightning. This acid in its concentrated form is so potent a poison, that it requires the most extreme care in the use of it, and more than one physiologist has been poisoned by it through the want of proper precaution while employing it for the purpose of experiment. If the nose of an animal be slowly passed over a bottle containing this poison, and the animal happen to inspire during the moment of the passage, it drops down dead instantaneously, just as when the poison is applied in the form of liquid to the tongue or the stomach. The vapour of chlorine possesses the property of arresting the poisonous effects of prussic acid, unless the latter be introduced into the system in a dose sufficiently strong to kill instantly; and, hence, when an animal is all but dead from the effects of prussic acid, it is sometimes suddenly restored to life by holding its mouth over the vapour of chlorine.

Examples of the transmission of gaseous bodies through the pulmonary membrane have been already fully described in the account of the passage of atmospheric air to the lungs, and of carbonic acid gas from the lungs, in natural respiration. But foreign substances may be mixed with or suspended in the atmospheric air, which it is the proper office of the pulmonary membrane to transmit to the lungs, and may be immediately carried with it into the circulating mass. Thus, merely passing through a recently-painted chamber gives to the urine the odour of turpentine. The vapour of turpentine diffused through the chamber is transmitted to the lungs with the inspired air, and passing into the circulation through the pulmonary membrane, exhibits its effects in the system more rapidly than if it had been taken into the stomach, and thence absorbed.

Vegetable and animal matter in a state of decomposition generates a poison, which when diffused in the atmosphere, and transmitted to the lungs in the inspired air, produces various diseases of the most destructive kind. The exhalations arising from marshes, bogs, and other uncultivated and undrained places, constitute a poison of a vegetable nature, which produces principally intermittent fever or ague. Exhalations accumulating in close, ill-ventilated, and crowded apartments in the confined situations of densely-populated cities, where no attention is paid to the removal of putrefying and excrementitious matters, constitute a poison chiefly of an animal nature, which produces continued fever of the typhoid character. It is proved by fatal experience that there are situations in which these putrefying matters, aided by heat and other peculiarities of climate, generate a poison so intense and deadly that a single inspiration of the air in which they are diffused is capable of producing instantaneous death; and that there are other situations in which a less highly concentrated poison accumulates, the inspiration of which for a few minutes produces a fever capable of destroying life in from two to twelve hours. In dirty and neglected ships, in which especially the bilge-water is allowed to remain uncleansed; in damp, crowded, and filthy gaols; in the crowded wards of ill-ventilated hospitals filled with persons labouring under malignant surgical diseases, or some forms of typhus fever, an atmosphere is generated which cannot be breathed long, even by the most healthy and robust, without producing highly dangerous fever.

The true nature of these poisonous exhalations is demonstrated by direct experiment. If a quantity of the air in which they are diffused be collected, the vapour may be condensed by cold and other agents, and a residuum of vegetable or animal matter obtained, which is found to be highly putrescent, constituting a deadly poison. A minute quantity of this concentrated poison applied to an animal previously in sound health, destroys life with the most intense symptoms of malignant fever. If, for example, ten or twelve drops of a fluid containing this highly-putrid matter be injected into the jugular vein of a dog, the animal is seized with acute fever; the action of the heart is inordinately excited, the respiration is accelerated, the heat increased, the prostration of strength extreme, the muscular power so exhausted, that the animal lies on the ground wholly unable to stir or to make the slightest effort; and, after a short time, it is actually seized with the black vomit, identical, in the nature of the matter evacuated, with that which is thrown up by an individual labouring under yellow fever. It is possible, by varying the intensity and the dose of the poison thus obtained, to produce fever of almost any type, endowed with almost any degree of mortal power. These facts, of which practical applications of the highest utility are hereafter to be made, may suffice to show the importance of the pulmonary membrane as an absorbing surface. By the extent and energy of its absorbing power, it is one of the great portals of life and health, or of disease and death.

The digestive surface is of much less extent than the pulmonary; it is less vascular; it is further removed from the centre of the circulating system, and it is covered with a thick mucus, which is closely adherent to it; hence its absorbing power is neither so great as that of the pulmonary membrane, nor do noxious substances in contact with it affect the system so rapidly. An appreciable interval commonly elapses between the introduction of a poison into the stomach and its action upon the system. An emetic is commonly a quarter of an hour before it begins to operate: arsenic itself is generally half an hour, and sometimes three quarters of an hour, before it produces any decided effect on the system: but at length a noxious substance applied to any part of the digestive membrane, is introduced into the circulating mass and produces its appropriate effects on the system, just as when it is in contact with the pulmonary tissue.

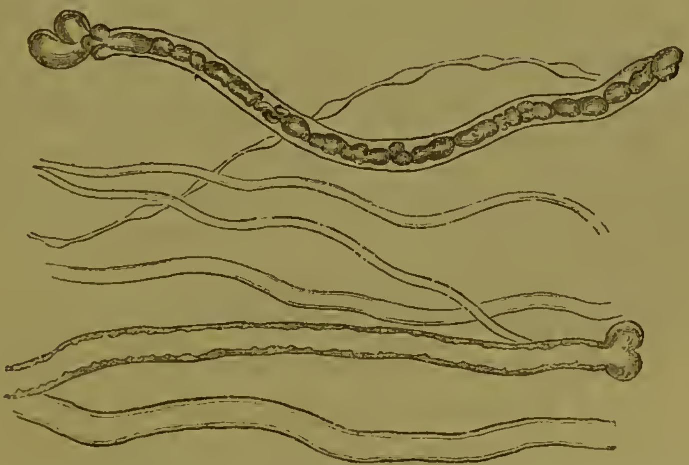
Over the external surface of the body or the skin, there is spread a thin layer of solid, inorganic, insensible matter, like a varnish of India-rubber. The obvious effect of such a barrier placed between the external surface of the body and external objects, is to moderate the entrance of substances from without, and the transmission of substances from within, that is, to regulate both the absorbing and the exhaling power of the skin. Hence the comparative slowness with which substances enter the system by the cutaneous surface; the impunity with which the most deadly poisons may remain for a time in contact with the skin, with which prussic acid, arsenic, corrosive sublimate, may be touched and even handled. The internal surface of the body is protected from the action of acrid substances introduced into the alimentary canal by a layer of mucus, through which an irritant must penetrate before it can pain the sentient nerve or irritate the capillary vessel; but were not a still denser shield thrown over the external surface, pain, disease, and death must inevitably result from the mere contact of innumerable bodies, which now are not only perfectly innoxious, but capable of ministering in a high degree to human comfort and improvement.

Immediately beneath the cuticle is a surface as vascular as it is sensitive, from which absorption takes place with extreme rapidity. Poison in very minute quantity introduced beneath the cuticle kills in a few minutes. Arsenic applied to surfaces from which the cuticle has been removed by ulceration produces its poisonous effects upon the system just as surely as when introduced into the stomach. The poisonous matter of small-pox and of cow-pox placed in almost inappreciable quantity by the lancet beneath the cuticle produces in a given time its specific action upon the system. When, in certain states of disease, with the view of bringing the system rapidly under the influence of a medicinal agent, the cuticle is removed by a blister, and the exposed surface is moistened with a solution of the substance whose action is required, the constitutional effects are developed with such intensity, that if extreme care be not taken in the employment of any deleterious substance in this mode, the result is fatal in a few minutes.

The phenomena which have been stated may suffice to illustrate the absorbing power of the general tissues and surfaces of the body; but superadded to this, there is carried on in particular parts of the system a specific absorption for which a special apparatus is provided.

The special apparatus of absorption, commonly termed the proper absorbent system, consists of the lacteal and lymphatic vessels and of the conglobate glands. The lacteals arise only from the intestines; the lymphatics, it is presumed, from every organ, tissue, and surface of the body. Both sets of vessels possess a structure strikingly analogous to that of veins, the common agents of absorption. The coats of the lacteals and lymphatics are somewhat thinner and a good deal more transparent than those of veins; yet thin and delicate as they are, they possess considerable strength, for they are capable of bearing, without rupture, injections which distend them far beyond their natural magnitude.

Fig. 98.



Human nerve-tubes, magnified 350 times. Three of them are fine, one of which is varicose, one of middling thickness and with a simple contour, and three thick, two of which are double contoured and one with grumous contents.

When fully distended, these vessels present a jointed appearance somewhat resembling a string of beads (Fig. 98). Each joint indicates the situation of a pair of valves. These valves are of a semilunar form, and are composed of a fold of the inner coat of the vessel. The convex side of the valve, in the lacteals, is towards the intestines; in the lymphatics towards the surfaces; in both towards the origins of the vessels. The valves allow the contents of the vessels to pass freely towards the main trunk of the system, but prevent any retrograde motion towards the origins of the vessels.

By continued pressure the resistance of the valves may be overcome, so that mercury may be made to pass from the trunk into the branches. When this is done in an absorbent trunk proceeding from certain organs, such as the liver, it is seen that the absorbents are distributed, arborescently, in such vast numbers that the surface of the viscus appears as if it were covered with a reticular sheet of quicksilver.

The internal coat of the small intestines has been shown to present a fleecy surface, crowded with minute elevations called villi, which give this surface an appearance closely resembling the pile of velvet. Each villus consists of an artery, a vein, a nerve, and a lacteal, united and sustained by delicate cellular tissue. After a meal the lacteals become so turgid with chyle that they completely conceal the blood-vessels and nerves, so that the surface of the intestine presents to the eye only a white mass, or a surface thickly crowded with white spots. These lacteals commence in the villi and pass up through the mesentery into the thoracic duct.

In the human body every vessel that can be distinctly recognised either as a lacteal or a lymphatic, passes, in some part of its course, through a conglobate or lymphatic gland (Fig. 91). These glands, small, flattened, circular or oval bodies, resembling beans in shape, are enclosed in a distinct membranous envelope. Their intimate structure has been already fully described. They are of various sizes, ranging from three to ten lines in diameter: they are placed in determinate parts of the body, and are grouped together in various ways, being sometimes single, but more often collected in masses of considerable magnitude. Numerous absorbent vessels, termed vasa inferentia, enter the gland on the side remote from the heart; a smaller number, called vasa efferentia, leave it on the side proximate to the heart. If mercury be injected into the vasa inferentia, it is seen to pass into a series of cells of the corresponding gland, and then to escape by the vasa efferentia; but if the gland be more minutely injected, as by wax, all appearance of cells vanishes; the whole substance of the gland seems then to consist of convoluted absorbents, irregularly dilated, and communicating with each other so intimately that every branch that leaves the gland appears to have been put in communication with every branch that entered it.

The motion of the fluid within the absorbent vessels, though not rapid, is energetic. If a ligature be placed around the thoracic duct in a living animal, the tube will swell and ultimately burst, from the rupture of its coat, in consequence of the force of the distension that takes place below the ligature. If the thoracic duct in the neck of a dog be opened some hours after the animal has taken a full meal, the chyle flows from the vessel in a full stream, and in the space of five minutes half an ounce of the fluid may be obtained. Yet this system of vessels is beyond the influence of the circulating blood: it has no heart to propel it; no current behind always in rapid motion to urge it onwards; it is therefore inferred that it is moved by a vital contractile power inherent in the vessels, analogous to, if not identical with, muscular contractility. The flow of blood through the arterial tubes is believed to be effected, in part at least, by such a contractile power, for this, among other reasons, that if in a living animal the trunk of an artery be laid bare, the mere exposure of it to the atmospheric air causes it to contract to such a degree that its size becomes obviously and strikingly diminished. The same phenomenon has been observed in the main trunk of the absorbent system. Tiedemann and Gmelin state that in the course of their experiments they saw the thoracic duct contract from exposure to the air.

The delicacy and transparency of the lacteals and lymphatics long concealed them from the view of the anatomist. The lacteals had indeed been occasionally seen in ancient times, but their office was altogether unknown. In the year 1563 Eustachius discovered the thoracic duct, but did not perceive its use. About half a century afterwards, in the year 1622, the lacteals were again one day by chance seen by Asellius, in Italy, while investigating the function of certain nerves. Mistaking the lacteals for nerves, he at first paid no attention to them; but soon observing that they did not pursue the same course as the nerves, and "astonished at the novelty of the thing," he hesitated for some time in silence. Revolving in his mind the doubts and controversies of anatomists, of which it chanced that he had been reading the very day before, in order to examine the matter further, "I took," he says, "a sharp scalpel to cut one of these chords, but scarcely had I struck it when I found a liquor white as milk, or rather like cream, to leap out. At this sight I could not contain myself for joy; but turning to the bystanders, Alexander Tadinus and the senator Septalius, I cried out Εὑρηκα! with Archimedes; and at the same time invited them to look at so rare and pleasing a spectacle, with the novelty of which they were much moved. But I was not long permitted to enjoy it, for the dog now expired, and, wonderful to tell, at the same instant the whole of that astonishing series and congeries of vessels, losing its brilliant whiteness, that fluid being gone, in our very hands, and almost before our eyes, so evanished and disappeared that hardly a vestige was left to my most diligent search." The next day he procured another dog, but could not discover the smallest white vessel. "And now," he continues, "I began to be downcast in my mind, thinking to myself that what had been observed in the first dog must be ranked among those rare things which, according to Galen, are sometimes seen in anatomy." But at length recollecting that the dog had been opened "athirst and unfed," he opened a third "after feeding him to satiety; and now everything was more manifest and brilliant than in the first case." The zeal with which he followed out the clue he had obtained is indicated by the number of dogs, cats, lambs, hogs, and cows which he dissected, and by the statement that he even bought a horse and opened it alive; but, he adds, "a living man, however, which Erasistratus and Herophilus of old did not fear to anatomize, I *confess* I did not open."

Nearly thirty years elapsed before the lacteals, which were long thought to terminate in the liver, were traced to the thoracic duct; and it was not until the year 1651, about eighty years after the discovery of Asellius, that the lymphatics were discovered, and that the whole of this portion of the absorbent system was brought to light.

Taking together the whole of the apparatus of absorption, the specific office performed by its several parts seems to be as follows:—

1. It is established that the lacteals absorb chyle, and that they refuse to take up almost every other substance which can be presented to them. Experimentalists are uniform in stating that however various the substances introduced into the stomach, it is exceedingly rare to find in the lacteals anything but chyle. These vessels appear to be endowed with a peculiar sensibility, derived from the nervous system, by which they are rendered capable of exerting an elective power, readily absorbing some substances and absolutely rejecting others.

2. The lymphatics absorb a far greater variety of substances than the lacteals, but not all substances indiscriminately; chiefly organised matter in a certain stage of purification; particles passing through successive processes of refinement.

3. The blood-vessels, and more especially the capillary veins, appear to absorb indiscriminately all substances, however heterogeneous their nature, which are dissolved or dissolvable in the fluids presented to them.

4. The absorbent glands appear by various modes, either by removing superfluous and noxious matters, or by the addition of secreted substances possessing assimilative properties, to approximate the fluid which flows through them more and more closely to the nature of the blood. Fatal effects result from the artificial infusion of minute portions even of mild substances into the blood. Hence the extended

and winding course which Nature causes the new matter formed from the food to undergo, even after its elaboration in the digestive apparatus, in order that, before it is allowed to mingle with the blood, its perfect purification and assimilation may be secured.

The activity or inactivity of the process of absorption is mainly dependent on the emptiness or the plethora of the system. There is a point of saturation beyond which the absorbent vessels, though in immediate and continued contact with absorbable matters, will take up no more. The nearer the system to this point the less active the process; the further the system from this point the more active the process. Thus, when an animal whose vessels are full to saturation is immersed in water, or exposed to humid air, its body does not increase in weight, and there is no sensible diminution of the water; but the longer an animal is kept without fluid, and the more it is exposed to the action of a dry air, the further its system is removed from the point of saturation, and exactly in that proportion, when it is brought in contact with water, is the diminution of the quantity of the fluid and the increase in the weight of the body. This law explains many circumstances of the animal economy,—why it is impossible to dilute the blood or any other animal fluid beyond a certain point, by any quantity of liquid which may be in contact with the external surface, or which may be taken into the stomach; why it is impossible to introduce nutrient matter into the system, beyond a certain point, by any quantity of food, which the digestive organs may convert into chyle; why, consequently, the bulk and weight of the body are incapable of indefinite increase; why that bulk and weight are so rapidly regained after long abstinence; and why the appetite is so keen, and the ordinary fulness and plumpness of the body are so soon restored, after recovery from fever and other acute diseases, when the digestive organs have been uninjured.

Different portions of the absorbent apparatus accomplish specific uses. With the absorbent action of the capillary blood-vessels and of membranous surfaces, every organic function, but more especially the processes of digestion and respiration, are intimately connected.

The specific absorption carried on by the lacteals has for its object the introduction of new materials into the system, for the reparation of the losses which it is constantly sustaining by the unceasing actions of life.

The specific absorption carried on by the lymphatics has a twofold object. First, the restoration of the surplus of nutritious material which transudes into the tissues, that it may pass a second time into the blood, in order to be subjected anew to the process of respiration, thereby affording them a second purification, and giving them new and higher properties; and, secondly, the regulation of the growth of the body, and the communication and preservation of its proper form.

It is the office of the lacteals to replenish the blood by constantly pouring into it new matter, duly prepared for its conversion into the nutritive fluid. It is the office of the lymphatics to preside over the distribution of the blood as it is deposited in the system in the act of nutrition. The lymphatics are the architects which mould and fashion the body. They not only regulate the extension of the frame, but they retain each individual part in its exact position, and give to it its exact size and shape. Growth is not mere accretion, not simple distension; it consists of a specific addition to every individual part, while all the parts retain the same exact relation to each other and to the whole. When a bone grows it does not increase in bulk by the mere accumulation of bony matter; but every osseous particle is so increased in length and breadth that the relative size of every part, and the general configuration of the whole organ, remain precisely the same. When a muscle grows, while the entire organ enlarges in bulk by the augmentation of every individual part, each part retains exactly its former proportions and its relative connexions. When the brain grows, a certain quantity of cerebral matter is added to every individual part, but at the same time the proportionate size and original form of each part, and the primitive configuration of the entire organ, are retained exactly the same. How is this effected? By a totally new disposition of every integrant particle of every part of every organ. New matter is not deposited before the removal of the old: the lymphatic, in the very act of removing the old, fashions a mould for the reception of the new, and then the capillary artery brings the new particle and deposits it with unerring exactness in the bed prepared for it. Thus, by removing the old materials of the body in a determinate manner, and thereby fashioning a mould for the reception of the new, the lymphatics may be said, in the strictest sense, to be the architects of the frame.

CHAPTER XVII.

OF THE FUNCTION OF EXCRETION.

In what excretion differs from secretion—Excretion in the plant—Quantity excreted by the plant compared with that excreted by the animal—Organs of excretion in the human body—Organisation of the skin—Excretory processes performed by it—Excretory processes of the lungs—Analogous processes of the liver—Use of the deposition of fat—Function of the kidneys—Function of the large intestines—Compensating and vicarious actions—Reasons why excretory processes are necessary—Adjustments.

The various matters contained in organised bodies, and even those which enter as constituent elements into their composition, are constantly removed from the system, and thrown off into the external world. The matters thus rejected are called excretions; and the various processes by which their elimination is effected constitute a common function termed excretion.

Excretion is the necessary consequence of the deterioration which all organised matter undergoes by the actions of life. The matters removed by the process consist of the waste particles of the body, or the particles expended in the vital actions, as the aliment contains the particles which replenish the waste, and compensate the expenditure.

The excretions are separated from the common organised mass by processes perfectly analogous to those comprehended in the great function of secretion. Excretion is only a particular form of secretion: the difference between the two functions is, that, in the former, the matter eliminated being either noxious or useless, is separated for the sole purpose of being rejected; while, in the latter, the matter eliminated, is destined to perform some useful purpose in the economy. Accordingly, the products of excretion are termed excrementitious; and those of secretion, recrementitious.

The chief matters excreted by the plant are oxygen, carbonic acid, air, water, in some few cases, under peculiar circumstances, ammonia and chlorine; and in still rarer cases, during the night, poisonous substances, as carburetted hydrogen, together with acrid, and even narcotic principles.

The forms under which these excretions are eliminated are exceedingly various. Sometimes the matter excreted is in the shape of gas, at other times it is in that of vapour, and at others in that of liquid. The chief gaseous exhalations are oxygen and carbonic acid; the vaporous exhalations consist principally of water, in the state of vapour; and the liquid exhalations are either pure water, or water holding in combination sugar, mucilage, and other proximate vegetable principles. Even the peculiar products formed by the vital actions of the plant, as the volatile oils, the fixed oils, the balsams, the resins, and perhaps, with the exception of gum, sugar, starch, and lignine, all the substances formed out of the proper juices of the plant, are true excretions; for these substances are fixed immoveably in the cells, sacs, or tubes which secrete and contain them: they are not consumed in the growth of the plant; they do not appear to be applied to any useful purpose in the economy; they are injurious, and even poisonous to the very plant in which they are formed when taken up by the roots and combined with the sap: as long as they remain in the plant they are isolated in the individual parts in which they are first deposited, until with the advancing age of the plant they lose their aqueous particles, and are finally dried up; they, therefore, possess all the essential characters of excrementitious substances.

The organs by which these matters are excreted are the leaves, the flowers, the fruits, the roots, and certain bodies called glands.

The gaseous and vaporous exhalations are effected chiefly by the leaves, which it has been shown, under the influence of the solar ray, are always pouring out a large quantity of oxygen, and still larger quantities of fluid in the state of vapour.

Similar matters are exhaled by the flowers either in the form of vapour or of liquid; and this exhalation commonly bears with it a peculiar odour, which proceeds from an essential oil, sometimes evaporated with the pollen, and at other times secreted by glandular bodies which have their seat in the petals.

Fruits, and especially green fruits, as raspberries, pears, apples, plums, apricots, figs, cherries, gooseberries, and grapes, pour out oxygen during the day, and carbonic acid gas during the night, and thus co-operate with leaves in carrying on the function of excretion.

The more elaborate excretions contained in special receptacles, and formed by diverse organs from the proper juices of the plant, descend chiefly by the bark, and are poured by the roots into the soil. These excretions, if reabsorbed by the roots, and reintroduced into the system of the plant that has rejected them, poison that plant. Consequently, two processes of deterioration are always going on in the soil; first, the absorption of the nutrient matter contained in it; and, secondly, the accumulation of excrementitious matter constantly poured into it by the growing plant. By the addition of manure, the soil is replenished with fresh nutritive materials; by a rotation of crops, it is purified from noxious excretions. It is a remarkable and beautiful adjustment, that excrementitious substances which are destructive to plants of one natural family, actually promote the growth of plants of a different species. Thus, if wheat be sown upon a tract of land proper for that grain, it may produce a good crop the first, the second, and perhaps even the third year, as long as the ground is what the farmers call in good heart. But, after a time, it will yield no more of that particular kind of corn. Barley it may still bear, and, after this, oats, and perhaps after these, peas, or some other species belonging to a different family. The excrementitious matter deposited in the soil by a preceding is absorbed by a succeeding crop; the matter excreted by the former serving as nutriment or stimulus to the latter. But though in this mode all noxious matter is removed from the soil, yet the ground at last becomes quite barren, in consequence of having parted with all its nutrient particles, and then it will yield no more produce until it is supplied with a new fund of matter. This new matter is afforded by vegetable or animal substances, in which, the principle of life having become extinct, the peculiar bond that held their particles together is dissolved. Leaves, flowers, fruits, bark, roots; hair, skin, horns, hoofs, fat, muscle, bone, the blood itself, whatever has formed a part of the organised body, now dead, and repassing through the process of decomposition, back to the simple physical elements, all its forms of beauty gone, and exhaling only matters highly deleterious to animal life, mixed with the soil, are recombined into new products, spring up into new plants, and thus reappear under new forms of beauty, and afford fresh nutriment to myriads of animals. The very refuse of the matters which have served as food and clothing to the inhabitants of the crowded city, and which, allowed to accumulate there, taint the air, and render it pestilential, promptly removed, and spread out on the surface of the surrounding country, give it healthfulness, clothe it with verdure, and endow it with inexhaustible fertility.

The quantity of matter excreted by the plant is proportionate to the energy of its vital actions. Hence it is always greatest in spring, when the tender leaves are beginning to shoot; gradually diminishes as autumn approaches; and, at last, as the leaves turn yellow, and the vessels which connect the leaves with the stalk dry up and are closed, it almost wholly ceases.

It is copious in proportion to the number of the leaves, and to the extent of the surface they present. From experiments performed as long ago as the year 1699, by Woodward, it appears that, of the whole quantity of water absorbed by the plant, the least proportion exhaled to that retained is as 46 or 50 to 1; in many cases it is as 100 or 200 to 1, and in some above 700 to 1. In one experiment, a plant which imbibed 2501 grains of water, increased in weight only three grains and a half: hence the dampness and humidity of the air in all places in which trees and the larger vegetables abound; more especially when the leaves are young, and most numerous and active;

and hence also the magnitude of the rivers in all extensive countries which are covered with forests.

Exhalation, scarcely appreciable in the night, is most abundant during the day under the influence of the solar light. If two plants of the same size are covered with two glass bells, and one be exposed to the sun's light, while the other is left in the shade, the inner surface of the former bell becomes covered with drops of water, while that of the second remains perfectly dry.

The absolute quantity of matter excreted by the plant is widely different in different species. According to Hales, in a sun-flower three feet and a half high, the leaves of which presented a surface of 5616 square inches, or 39 square feet, the greatest quantity exhaled in twelve hours, during the day, was one pound fourteen ounces avoirdupois; the medium quantity one pound four ounces. In a middle-sized cabbage, the greatest quantity exhaled was one pound nine ounces; the medium quantity one pound three ounces. In a vine, the greatest quantity exhaled was six ounces; the medium quantity five ounces. In a young apple-tree having 163 leaves, the surface of which was equal to 1589 square inches, or 11 square feet, the greatest quantity exhaled was eleven ounces; the medium quantity nine ounces. Martino calculated the quantity exhaled by a cabbage, in the twenty-four hours, at twenty-three ounces; by a young mulberry-tree, eighteen ounces; and, by a maize plant, seven drachms.

Supposing the weight of the human body to be 160 pounds, and the weight of a sun-flower 3 pounds, the relative weights of the two bodies will be as 160 to 3, or as 53 to 1. The surface of such a human body is equal to 15 square feet, or 2160 square inches; the surface of the sun-flower is 5616 square inches, or as 26 to 10. The quantity perspired in the twenty-four hours by an ordinary-sized man, according to the estimate of Keill, is about thirty-one ounces. Allowing two ounces for the exhalation during the beginning and the ending of the night, the quantity exhaled by the plant, in the same time, is twenty-two ounces; so that the perspiration of a man to that of a sun-flower is nearly as 141 to 100, though the weight of the man to that of the sun-flower is as 53 to 1. Taking bulk for bulk, the plant imbibes seventeen times more fresh fluid than the man, partly, no doubt, for the reason assigned by Hales—because, "the fluid which is filtered through the roots of the plant is not near so full freighted with nutrient particles as the chyle which enters the lacteals of the animal; the plant, therefore, requires a much larger supply of fluid."

As soon, in the animal series, as organs are formed distinct from the homogeneous mass of which the minute and simple beings placed at the bottom of the scale appear to consist, these organs are appropriated, at least in part, to the function of excretion. In the human being.

six organs take a part, and are chiefly appropriated to this function—namely, the skin, the lungs, the liver, the adipose tissue, the kidneys, and the intestinal canal. All these organs serve other purposes in the economy; but still the removal, in some specific form, of excrementitious matter from the system, is a most important part of the office of each.

The skin, to which are assigned numerous and highly important offices, seems to be specially constructed for performing the function of excretion. It is composed of three layers, of which the internal is called the cutis, or true skin; the external the cuticle, or scarf skin; and the middle, by which the other two are united, the rete mucosum. The latter is indistinct, excepting in the negro, in whom it is the seat of colour.

The cutis, or true skin, is a dense membrane, composed of firm and strong fibres, interwoven like a felt. Its internal surface is marked by numerous depressions, which receive processes of the adipose tissue beneath. Under its external surface, which the microscope shows to be bounded by a thin, pellucid, structureless membrane, is spread a delicate and complex network of vessels, termed the vascular plexus, of such extent and capacity that, in the natural state of the circulation, a very large proportion of the whole blood of the body is constantly flowing in these blood-vessels of the cutis. A prodigious number of nerves accompany the cutaneous blood-vessels, some derived from the organic, and others from the sentient portion of the nervous system. The organic nerves endow the arteries with the power of performing the organic processes proper to the cutis, which are principally of an excrementitious nature. The sentient nerves communicate to every point of the external surface of the cutis the exquisite degree of sensibility possessed by the skin. Innumerable absorbent vessels terminate at the same points, with the capillary arteries and the sentient nerves.

The extreme smoothness and softness natural to the skin is communicated to it by a number of follicles which are placed in the cutis, and are termed sebaceous, from the oily substance they secrete. It is the matter secreted by these organs which communicates to the animal body the odour peculiar to it, on which the scent depends.

In many parts the cutis is perforated obliquely by hairs, which spring from little bulbs beneath it, to which the growth of the hairs is confined. The human hair consists of fine tubes filled with an oily matter. This matter is either of a black, red, yellow, or pale colour, as the hair is black, red, yellow, or white.

The nails are products formed by the cutis, and are essentially the same as the cuticle.

By long-continued boiling the cutis is resolvable into gelatin, which by evaporation becomes glue, and by combining with tannin and the extractive of oak bark is converted into leather.

The third portion of the skin, the cuticle, is a thin, elastic membrane spread over the external surface of the cutis, from which it is easily detached, by the action of a blister in the living, and by the process of putrefaction in the dead body. It is without vessels and nerves, and consequently it is insensible. It is formed by the cutis, of cells which grow upon its outer surface: these are at first rounded and soft, but continually others more recent are growing beneath them so as to raise them further and further from the cutis, the common source of their nutriment; and as they thus are supplanted by younger, they flatten and mat together, at the same time losing all their vital properties, and growing horny to form an insensible covering to the tender cutis. When any portion of this covering is removed, it is renewed with great rapidity. Since it is subject to constant waste from friction, and is much increased by pressure, as is manifest in the palms of the hands and the soles of the feet, its formation must be continual; yet even in the fœtus it is thicker in the parts where pressure is ultimately to be made than in the other parts of the body.

The cuticle is a sheath in which the body is enclosed for the purpose of restraining the organic actions which take place at its surface, and for tempering the sentient impressions received there. For restraining the organic actions it is fitted by the cohesion of its parts, which is such as to receive and transmit any fluid very slowly, as is manifest from the dryness of its surface when it is raised in a blister, and from the extreme rapidity with which the cutis dries, until it becomes as hard as parchment, when the cuticle is removed from it in the dead body.

Diffused over every part and particle of the cutis is the seat of common sensation, that cognizance may be taken of the presence of external objects. Restricted to particular points, the tip of the fingers is the seat of one of the special senses, that of touch. Had the nerves which communicate to this extended surface its acute sensibility been placed in direct contact with external bodies, intolerable pain would have been the result; but by covering this surface with an inorganic and insensible substance, yet so thin that it is a pellicle rather than a membrane, the organ of sense is shielded, while the delicacy of sensation is not impaired. But the control of the organic process and the protection of the sentient nerve are not the only offices performed by the cuticle; it serves further to hide what it is undesirable to have constantly in view. All that is beautiful in the blood as an object of sense is rendered visible through the cuticle, in the bright and rosy hue of health, at the same time that every process, the sight of which would excite anxiety or terror, is effectually concealed.

The skin, an organ of secretion, an organ of absorption, an organ of excretion, and an organ of sense, is thus the immediate seat of three organic processes and of one animal process.

The chief excretion performed by the skin, in the human body, is commonly known under the name of perspiration. The perspiration is either sensible or insensible. Sensible perspiration is the liquid commonly called the sweat. Insensible perspiration consists of a vapour which, under the ordinary circumstances in which the body is placed, is invisible. The invisible vapour is constantly exhaling; the visible liquid is only occasionally formed. The quantity of matter carried out of the system under the form of invisible vapour is much greater than that lost by the visible liquid.

That a quantity of matter is incessantly passing off from the surface of the skin, under the form of an invisible vapour, is proved by the following facts:—

1. If the hand and arm are enclosed in a glass jar, the inner surface of the glass soon becomes covered with moisture.

2. If the tip of the finger be held at about the twelfth of an inch from a mirror, or any other highly-polished surface, the surface rapidly becomes dimmed by the vapour which condenses upon it in small drops, and which disappear on the removal of the finger.

3. If the body be weighed at different periods, an accurate account being taken of the ingesta and the egesta, it is found to undergo a loss of weight sensibly greater than can be attributed to any of the visible discharges: this loss must be owing to the transmission of a quantity of matter out of the body, under the form of invisible vapour.

The matters excreted under the form of perspiration are separated from the blood by a true and proper secretion, like the other secretions of the body. The process by which this is effected is called transudation. The matter of transudation deposited on the surface of the skin by a vital function is removed from the body by evaporation, a physical process which consists of the conversion of a liquid into a vapour by the addition of heat. Consequently the process of perspiration is a cooling process, and it is chiefly by the increase of the perspiration that the body is enabled to bear the intense degrees of heat which it has been shown to be capable of sustaining. Sitting one day in repose in the shade during the intense heat of an American summer's day, the skin freely perspiring at every pore, Dr. Franklin happened to examine the temperature of his body with a thermometer. He found that the temperature of his body was several degrees lower than that of the surrounding air. The physiologists who exposed themselves in heated chambers, for the sake of ascertaining the greatest degree of heat which the human body is capable of enduring, perspired profusely during the experiment. The artisans who carry on their daily occupations in elevated temperatures perspire most profusely. Under such circumstances, caloric is communicated to the human body just as freely as to inorganic matter, yet it does not injure the body, because it does not accumulate in the system, but is immediately expended in supplying the heat necessary to convert the water, which is poured out upon the skin, into vapour. In this manner that surface of the body at which, under ordinary circumstances, a large portion of its animal heat is generated, is the very surface at which, under extraordinary circumstances, cold is generated, and the heat of the system positively reduced.

The physical process of evaporation would go on to a certain extent, though the vital function of transudation did not exist, and does go on in the dead body when the vital function is at an end. An organic tissue enclosing a liquid may not be porous enough to give passage to a single drop of liquid, and yet sufficiently porous to admit air. In this case the air in contact with the tissue dissolves the liquid in its interior, and carries it off in the form of invisible vapour; hence liquids contained in organic bodies in contact with the air diminish in quantity by evaporation. But if an animal be placed in air saturated with moisture, and of the same temperature as its own, the air can no longer deprive that animal of a single particle of its moisture: evaporation from the body, in such a condition of the air, is suppressed. On the other hand, when an animal is placed in air saturated with moisture, and of the same temperature as its own, so far is transudation from being suppressed, that the sweat streams from every part of the external surface of the body. By modifying the condition of the air in regard to its hygrometrical state and its temperature, the result of the physical process and of the vital function may thus be separated from each other, and the amount of each may be ascertained with perfect exactness. Now, by numerous experiments on the cold-blooded vertebrata, placed under such conditions of the air, it is found that, in these animals, perspiration by evaporation is to that by transudation as 6 to 1. But since the human body presents to the air an immense extent of surface over which is constantly flowing a large proportion of the whole quantity of blood contained in the system, the loss by the physical process compared with that by the vital function must be still greater in man than in the cold-blooded animal.

Taking together the average quantity of matter removed from the human body by both processes, or the whole loss of weight sustained from perspiration, on the comparison of the results of many observations, it is estimated to vary from twenty ounces in the twenty-four hours of the colder, to forty ounces in the warmer climates of Europe. Keill estimated it at thirty-one ounces. In the climate of Paris it is stated to be thirty ounces.

By the delicate tests of modern chemistry, various substances are found to be contained in the aqueous fluid which constitutes the great proportion of the matter of perspiration, namely, an acid, probably the lactic, a small proportion of animal matter, some alkaline and earthy salts, and an oily or fatty substance, probably derived from the sebaceous follicles. All these matters are so analogous to the constituents of the serum of the blood as to leave little ground for doubt that they are merely separated from this part of the blood as it is flowing through the complex network of vessels spread over the surface of the cutis.

The skin, when in contact with the air, also separates a portion of carbon from the blood, and to the extent in which it does this it is auxiliary to the lungs; but the quantity of carbonic acid excreted by the skin is small and variable in amount. The primary office of the skin as an organ of excretion is to relieve the blood of its superabundant watery particles, that is, to remove from the system its superfluous hydrogen.

A full account has been given of the primary office of the lungs, which, it has been shown, is to decarbonize the blood. The details of the calculations have been stated, from which it is estimated that 10 ounces and 116 grains of carbon are daily exhaled by the lungs under the form of carbonic acid; and the reasons have been assigned which favour the conclusion that the carbonic acid expired is not formed immediately in the lungs by the combination of the oxygen of the atmospheric air with the carbon of the blood; but in the system, where the oxygen taken into the blood at the lungs unites with carbon, the carbonic acid resulting from the combination passing as soon as formed into the capillary veins. The blood contained in these vessels, thus become venous, returns to the lungs, where it gives off the carbonic acid accumulated in it, and by that depuration again assumes its arterial character.

It has been shown that, together with the carbonic acid, which passes off in the inspired air, there is always present a quantity of aqueous vapour. This aqueous vapour is not visible at the ordinary temperature of the air in its ordinary hygrometric state, because the water is then dissolved in the air, and is carried off in the form of invisible vapour; but it becomes abundantly manifest at a low temperature, or when the air is loaded with moisture. By the removal of this aqueous vapour, the lungs assist the skin in the depuration of the blood. The water transpired by the lungs, like that perspired through the skin, is separated from the blood by a true and proper secretion constituting the pulmonary transudation. It is commonly estimated that the lungs exhale about one-third as much as the skin, or fifteen ounces daily. Dalton estimates it at twenty-four ounces.

These estimates of the quantity of fluid lost by cutaneous and pulmonary transpiration relate to the quantities lost at the ordinary external temperatures in which the human body is placed. The quantity lost when the body is exposed to an elevated temperature is prodigiously increased. It did not occur to the physiologists, whose experiments have been detailed, to ascertain this by causing themselves to be accurately weighed immediately before they entered their heated chamber and immediately after they left it. Having heard that the loss daily sustained by the workmen employed in gas-works is very extraordinary, I endeavoured to ascertain the amount of it with exactness. This I was enabled to accomplish by the assistance of Mr. Monro, the manager of the Phœnix Gas Works, and of Mr. Cooper. The following are the experiments by which this has been ascertained.

Experiment I.—November 18, 1836, at the Phœnix Gas Works, Bankside, London.

Eight of the workmen regularly employed at this establishment in drawing and charging the retorts and in making up the fires, which labour they performed twice every day, commonly for the space of one hour, were accurately weighed in their clothes immediately before they began and after they had finished their work. On this occasion they continued at their work exactly three-quarters of an hour. In the interval between the first and second weighing, the men were allowed to partake of no solid or liquid, nor to part with either. The day was bright and clear, with much wind. The men worked in the open air, the temperature of which was 60° Fahr. The barometer 29° 25′ to 29° 4′.

	Weight of the Men before they began their work.				Weight of the Men after they had finished their work.				Loss.	
	cwt.	qr.	lbs.	oz.	cwt.	qr.	lbs.	oz.	lbs.	oz.
Michael Griffiths . .	1	1	14	10	1	1	12	2	2	8
John Kenny	1	0	26	10	1	0	24	1	2	9
John Ives	1	0	14	2	1	0	11	8	2	10
James Finnigan . . .	1	1	10	6	1	1	7	0	3	6
William Hummerson .	1	0	24	4	1	0	20	8	3	12
Timothy Frawley . .	1	1	8	10	1	1	4	12	3	14
Patrick Nearey . . .	1	1	14	10	1	1	10	8	4	2
Bryan Glynon . . .	1	1	0	4	1	0	24	1	4	3

Experiment II.—Nov. 25, 1836.

Day foggy, with scarcely any wind. Temperature of the air 39° Fahr., barometer 29° 8′. On this occasion the men continued at their labour one hour and a quarter.

	Before.				After.				Loss.	
	cwt.	qr.	lbs.	oz.	cwt.	qr.	lbs.	oz.	lbs.	oz.
Patrick Murphy . . .	1	1	0	0	1	0	27	2	0	14
John Broderick . . .	1	0	9	4	1	0	8	0	1	4
Michael Macarthy . .	1	0	11	9	1	0	10	3	1	6
Michael Griffiths . .	1	1	15	8	1	1	13	2	2	6
James Finnigan . . .	1	1	12	4	1	1	9	12	2	8
Bryan Duffy	1	1	11	12	1	1	9	0	2	12
John Didderick . . .	1	1	11	5	1	1	8	8	2	13
Charles Cahell . . .	1	1	4	5	1	1	1	6	2	15

Charles Cahell, the man who on this occasion lost the most, was weighed previously to the commencement of his work, with all his clothes off, excepting his shirt, which was kept dry and put on him again when weighed a second time at the end of his work. He was then immediately put into a warm bath at 95° Fahr., and kept there half an hour: he complained of being weak and faint, and when reweighed had gained half a pound.

Experiment III.—June, 4, 1837.

Day clear, with some wind. Temperature 60° 5′.

	Before.				After.				Loss.	
	cwt.	qr.	lbs.	oz.	cwt.	qr.	lbs.	oz.	lbs.	oz.
Robert Bowers . . .	1	1	19	0	1	1	17	0	2	0
William Mullins . . .	1	1	3	0	1	1	1	0	2	0
Charles Cahell . . .	1	1	2	0	1	1	0	0	2	0
John Kenny	1	0	22	2	1	0	19	8	2	10
Bryan Glynon . . .	1	0	27	0	1	0	24	4	2	12
John Haley	1	1	4	0	1	1	1	4	2	12
Benjamin Faulkner . .	1	1	15	14	1	1	13	0	2	14
Michael Griffiths. . .	1	1	8	8	1	1	5	8	3	0
John Broderick . . .	1	0	4	6	0	3	27	8	4	14
John Didderick . . .	1	1	6	12	1	1	1	10	5	2

The two last men worked in a very hot place for one hour and ten minutes; all the rest worked about one hour. Michael Griffiths, as soon as he had finished his work, was put into a bath at 98°, where he remained half an hour. He was reweighed on coming out of the bath, and had lost 8 oz.

From these observations it appears that, towards the end of November, when the the temperature of the external air was 39°, and the day was foggy and without wind, the greatest loss did not amount to 3 lbs. (2 lbs. 15 oz.), the least loss was 14 oz., and the average loss was 2 lbs. 3 oz.

In the middle of the same month, when the temperature of the air was 60°, and the day was clear with much wind, the greatest loss was 4 lbs. 3 oz., the least loss was 2 lbs. 8 oz., and the average loss was 3 lbs. 6 oz.

In June, when the temperature of the external air was 60°, and the day exceedingly bright and clear, without much wind, the greatest loss was 5 lbs. 2 oz., the next greatest loss was 4 lbs. 14 oz., the least loss was 2 lbs., and the average loss was 2 lbs. 8 oz.

The same individuals lose very different quantities at different times. Thus, James Finnigan in the first experiment lost 3 lbs. 6 oz., in the second 2 lbs. 8 oz. Michael Griffiths in the first experiment lost 2 lbs. 8 oz., in the second 2 lbs. 6 oz., and in the third 3 lbs.; while John Kenny in the first experiment lost 2 lbs. 9 oz., and in the third experiment, which was the second to which he was subjected, he lost very nearly the same, namely, 2 lbs. 10 oz. On the other hand, Bryan Glynon in the first experiment lost 4 lbs. 3 oz., and in the third experiment, which was the second to which he was subjected, he lost no more than 2 lbs. 12 oz.

In one case, when a man who had lost 2 lbs. 15 oz., the greatest quantity lost by any of the men examined during that day, was put into a hot bath at 95°, and reweighed on coming out of the bath, where he had remained exactly half an hour, it was found that he had gained half a pound. On the other hand, when a man who had lost 3 lbs. was put into a hot bath at 98°, and kept there for half an hour and reweighed, it was found that he had lost exactly half a pound.

It had been our intention to have pursued these experiments, with the view of ascertaining the influence of the hygrometrical state of the air on transpiration, as well as the absorbing power of the skin, under circumstances so favourable to the activity of that power, but the investigation was unavoidably discontinued.

According to the prevalent opinion, the liver is the cause of a large proportion of the maladies which afflict and destroy human life. It certainly exercises an important influence over health and disease, the true reason of which is but little understood by those who attribute most to its agency.

The liver is an organ of digestion and an organ of excretion.

It is an organ of digestion in a twofold mode:

1. By the secretion of a peculiar fluid, through the direct action of which chyme is converted into chyle. The several phenomena attending this operation have been fully described.

2. By subjecting alimentary matters which have been partly acted on by the stomach and intestines to a second digestion.

It has been shown that the veins which return the blood from the digestive organs, the stomach, the intestines, and the mesentery, together with the veins of the spleen, the omentum and the pancreas, instead of pursuing a direct course to the right side of the heart in order to transmit their contents by the shortest route to the lungs, as is the case with all the other veins of the body, unite together and form a large trunk termed the vena portæ, which enters the liver and ramifies through it in the manner of an artery. It has been further shown that the bile is secreted from the venous blood contained in this vessel by its capillary branches spread out on the walls of the biliary ducts, that the trunk of this vein, unlike that of any other, is encompassed with organic nerves, which accompany its subdivisions, and are spread out upon its capillary branches just as an organic nerve is spread upon an artery, and that thus, as this vessel performs the function of an artery, it has the structure and distribution of an artery.

The veins which unite to form the vena portæ take up, by their capillary branches, certain portions of the contents of their respective organs, and bear those contents directly into the venous current. The capillary veins of the stomach take up certain parts of the contents of the stomach, it would appear the fluid substances received with the aliment more especially; the capillary veins of the duodenum take up certain portions of the contents of the duodenum, and so on of the capillary veins of the spleen, intestines, and all the organs whose veins combine to form the vena portæ. Certain products of digestion must, then, be constantly poured, by the capillary veins of the digestive organs, into the blood of the vena portæ.

Accordingly, on the examination of animals soon after a meal, streaks of a substance like chyle are often observed in the blood of the vena portæ. It is further established by numerous experiments, that if alcohol, gamboge, indigo, and other odoriferous and colouring matters, are mixed with the food, their presence is manifest in the blood of the digestive organs, and more especially in the blood of the mesenteric veins and in that of the vena portæ, while no trace of these substances is ever found in the lacteals.

The lacteals, it has been shown, are special organs appropriated to the performance of a specific function, that of absorbing chyle. To fit them for this office, they are endowed with an elective power, by virtue of which they select, from the alimentary mass, that portion of it only which is converted into chyle; in a natural and healthy state they would appear to be incapable of absorbing any other substance excepting pure chyle. But in the digestive organs there is always present much nutritive matter not yet converted into proper chyle, and with this matter there are mixed foreign substances not strictly alimentary. These unassimilated matters and foreign substances, absorbed by the capillary veins or by the absorbent vessels, or by both, are conveyed directly into the vena portæ, by which vessel they are transmitted to the liver, where they undergo a true and proper digestion. After undergoing this digestion in the liver, they are sent by a short course to the heart, and thence to the lungs, where they are assimilated into, or at least commingled with, arterial blood, and, with arterial blood, are transmitted to the system. The substances subjected to this hepatic digestion, which is as real as that effected in the stomach and duodenum, do not appear to enter the lacteals at all; they have therefore a shorter course to traverse, and probably a proportionately less elaborate process to undergo, before their transmission to the lungs and their final entrance into the arterial system.

What the particular substances are for which this slighter digestive process suffices is not known with certainty. There is, however, reason to suppose that they consist chiefly of liquids, while there is direct evidence that vinous and spirituous liquids enter the system through this shorter course; since these fluids are often abundantly manifest in the blood of the vena portæ, when not the slightest trace of them can be detected in the lacteal vessels.

According to this view, the liver is a second digestive apparatus, completing what the first commences, or effecting what that is incapable of accomplishing; and this view assigns the reason why certain fluids taken into the stomach sometimes appear in the secretions and excretions with such astonishing rapidity; why the liver so constantly becomes diseased when highly stimulating substances, not properly alimentary, are mixed with the food, and more especially when ardent spirits or the stronger wines are largely and habitually taken; why the sympathy is so intimate and intense between the stomach and the liver and the liver and the stomach, both in health and disease.

The second function performed by the liver is that of excretion. The excrementitious matter eliminated from the blood by the liver is contained in its peculiar secretion, the bile. The bile consists of two portions, an assimilative part which combines chemically with the chyle, purifying and exalting its nature; and an excrementitious part, which combines with the residue of the aliment.

The excrementitious part of the bile contains a large proportion of carbon and hydrogen. Carbon and hydrogen abound in venous blood; venous blood in large quantity is sent to the liver to afford the materials for the the secretion of bile; consequently, the more copious the secretion of bile the greater the quantity of carbon and hydrogen abstracted from venous blood. It follows that, by this elimination of carbon and hydrogen from the blood, the liver is auxiliary, as an organ of excretion, to the skin and the lungs.

But it is well worthy of remark, that although the liver at all times assists the skin and the lungs in carrying on the process of excretion, it does this most especially under circumstances which necessarily enfeeble the action of the cutaneous and pulmonary organs.

Less carbon is expelled from the lungs in summer than in winter; at a high than at a low temperature; consequently by a long-continued exposure to intense heat, as in the hot months of summer, and still more by a continual residence in a warm climate, an accumulation of carbon in the blood is favoured. A part of this excess is removed by the increased exhalation from the skin. The skin, however, is the chief outlet, not for carbon, but for hydrogen; and accordingly by the increased perspiration hydrogen is largely removed. Hydrogen and carbon compose fat. The deposition of fat, could it go on to the requisite extent, would afford an adequate consumption for the superabundant carbon; but the formation of fat is prevented by the dissipation of the hydrogen. Under such circumstances, when the lungs cannot carry off the requisite quantity of carbon, nor the adipose tissue compensate for its diminished activity by the deposition of fat, the liver, taking on an increased action, secretes an extraordinary quantity of bile. In this manner the superfluous carbon, instead of being removed in the ordinary mode, by the pulmonary artery through the lungs, under the form of carbonic acid gas, is excreted by the vena portæ, through the liver, under the form of bile, while the superabundant hydrogen is removed by the increased quantity of perspiration; and thus the accumulation of these inflammable matters in the system is effectually prevented.

By the deposition of fat in the adipose tissue material assistance is afforded to the excretory action of the skin, the lungs, and the liver. Fat is composed essentially of carbon and hydrogen; it contains no nitrogen and very little oxygen. It is deposited whenever an excessive quantity of nutritive matter is poured into the blood, and especially when at the same time the different secretions and excretions ordinarily formed from the blood are diminished. The primary object of this deposition is to relieve the circulation of a load which would embarrass and ultimately stop the actions of life. It serves, however, a secondary purpose, that of forming a storehouse of nutritive matter, duly prepared for supplying the wants of the system, in case the body should be placed under circumstances in which the digestive organs can no longer receive food or no longer convert it into chyle.

Thus hybernating animals, which pass many months without taking food, accumulate a store of fat before they fall into the state of torpor. Marmots and dormice subsist on this store during the winter, and hence, when spring awakens them from their torpor, they are always in a state of extreme emaciation. Birds and other animals which live on food procured with difficulty in the winter, become unusually fat in the autumn.

During fever and other acute diseases, when little food is received, and still less converted into chyle, the extreme emaciation which the body undergoes is owing partly to the disappearance of the fat, which is taken up by the absorbents and carried into the blood, in order to compensate for the deficiency of nutrient matter supplied by the digestive organs.

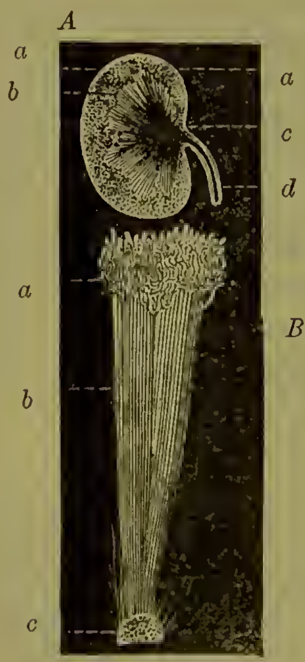
The chief depositories of the fat are those interstitial spaces of the body in which a certain quantity of soft but tenacious substance is required to obviate pressure or to preserve symmetry. A large quantity is also placed immediately beneath the skin; in the interstices of muscles; along the course of blood-vessels and nerves; in the omentum, where it is spread like a covering over the viscera of the abdomen; in the mesentery and around the kidneys.

Fat is a bad conductor of heat; consequently the layer which is spread over the external surface immediately beneath the skin, and that which is collected in the interior of the omentum, must be useful in preserving the heat of the body. Fat persons bear cold better than lean persons. Animals which inhabit the northern climates are enveloped in prodigious quantities of fat. Where the accumulation of this substance would produce deformity or interfere with function, as in the eyelids, within the skull, &c., not a particle is ever deposited. About the joints it would impede motion; in the eyelids it would render the face hideous and obstruct vision; and within the skull, a cavity completely filled with the brain—an organ impatient of the slightest pressure—had a substance been placed, the quantity of which is liable to be suddenly trebled or quadrupled, changes in the system which now produce no inconvenience would have been fatal. Thus, while provision is made at once to exonerate the system from too great a load of nourishment, and to lay up the superfluous matter, as in a magazine, to be ready for future use, the most extreme care is taken to deposit the store in safe and convenient situations.

The excretory organs and processes, hitherto considered, have for their object the removal from the blood of its superfluous carbon and hydrogen; the element peculiar to the animal body, azote, is eliminated by the kidneys—glandular organs which possess a highly complex structure. (Fig. 99.)

But besides the removal of the superfluous azote, the fluid secreted by the kidneys would appear to be a general outlet for whatever is not required in the system, and for the removal of which no specific apparatus is provided. Chemical analysis shows that, in different states of the system, the following substances are contained in this fluid:—water, free phosphoric acid, phosphate of lime, phosphate of magnesia, floric acid, uric acid, benzoic acid, lactic acid, urea, gelatin,

Fig. 99.



Structure of the kidneys.—*A*, vertical section of a kidney. *a*, cortical substance; *b*, tubular substance; *c*, calyx and pelvis; *d*, canal of the ureter. *B*, intimate structure of this gland. *a*, terminal portion of the urinary tubes; *b*, medullary portion of these same tubes; *c*, their termination in the calyx.

albumen, lactate of ammonia, sulphate of potash, sulphate of soda, fluate of lime, muriate of soda, phosphate of soda, phosphate of ammonia, sulphur, and silex.

This catalogue itself suggests the idea that when any matter employed in carrying on the functions is in excess, or when it has become decayed, or is decomposed and is not eliminated by any other excretory process, it is taken up by the absorbents, poured into the veins, and so conveyed in the course of the circulation to the kidneys, by which organs it is separated from the blood, and thence by an appropriate apparatus carried out of the system. The specific matter secreted by the kidneys is that termed urea.

Organs appropriated to the removal of substances from the blood, capable of becoming deleterious by their accumulation, generally, in a state of health, perform their office so perfectly that the matters which it is their part to excrete are eliminated almost as quickly as they enter the blood, so that they are seldom present in the circulating fluid in sufficient quantity to be detected by the most delicate chemical tests. But by the removal of the excretory organ, or by the suppression of its function, the excretory matter accumulates in the blood, and is then readily detected. A decisive experiment disclosed that this is the case with regard to urea. The kidneys were removed from a living animal. The operation did not appear to be productive of material injury for some time; but at length symptoms denoting the presence of a poison in the blood arose, and the animal died. The blood was carefully examined after death. It was found to contain a much larger quantity than ordinary of urea. It is probable that the chief office of the kidney is to separate the urea from the other ingredients of the blood, and to convey it to the organs which are destined to carry it out of the body.

It is estimated that about a thousand ounces of blood pass through the kidneys in the space of an hour; itself a sufficient indication of the importance of the excretion performed by this organ, and an adequate source of the matter actually excreted, although, under ordinary circumstances, distributed through the circulating mass in quantities so minute as to be almost inappreciable.

Out of the body urea putrefies with great rapidity. When retained in the system by the extirpation of the kidney, or by placing a ligature around the ureter, such is the septic tendency communicated to the blood that signs of putrescency become manifest even during life, and after death all the soft parts of the body are reduced to a state of putrefaction with extreme rapidity. The suppression of the secretion in the human body, or the undue retention of the matter secreted, induces fever of a malignant kind, in which the symptoms that denote a highly putrid taint in the system are rapidly developed. But for the labour of the kidney, then, a substance would accumulate in the blood, which would quickly lead to the decomposition of the body.

It has been shown that the mucous membrane which lines the alimentary canal is studded in its whole extent with glands, which secrete from the blood a large quantity of fluid. These secretions go on without interruption, whether food be taken or not, so that there may be copious alvine evacuations though not a particle of food enter the stomach; and the separation of the matter eliminated from the blood by this extended membrane can no more be dispensed with than that by the skin or the lungs. There is, too, a most intimate sympathy between the secretion of the membrane that lines the internal surface of the body and that carried on by its external covering; any disorder of the one immediately and powerfully disturbs the natural course of the other: hence the diarrhœa, so often produced by the application of cold to the external skin, and the diseases of the skin, so constantly connected with a disordered state of the mucous membrane of the intestines.

It is the special office of the large intestines to prepare for its removal, and to carry out of the system the residue of the aliment, together with the excrementitious portion of the bile.

Supposing the ingesta in twenty-four hours to be of food 6 pounds, or 96 ounces, and of oxygen retained in the system 4 ounces, in all 100 ounces, it is estimated that the egesta will be, in twenty-four hours, by the skin, 34 ounces, by the lungs 17 ounces, by the intestines 6 ounces, by the kidneys 40 ounces, and by various other excretions 3 ounces, in all, 100 ounces. These calculations must, of course, be taken only as approximations to the truth, and as ascribing rather the relative than the positive quantities of matter excreted.

Whatever be the absolute quantity or the form of the excretions, it is clear, from the preceding account, that there is constantly removed from the system by the skin a large portion of hydrogen and some carbon; by the lungs a large portion of carbon and some hydrogen; by the liver a large portion of hydrogen and some carbon; by the kidneys a large portion of azote; by the large intestines the residue of the aliment; while, by the deposition of fat, the superabundant nutriment withdrawn from the current of the circulation is laid up in store in some safe part of the body.

Most of the processes which have been described are mutually compensating and vicarious. Besides the office which each habitually performs, it is capable of having its action occasionally increased, for the purpose of supplying the deficiency of one or more of its fellows. If perspiration by the skin languish, transudation by the lungs increases; if neither the skin nor the lungs be able to remove the superfluous hydrogen and carbon, these inflammable substances are carried out of the system by the liver in an augmented secretion of bile. If the action of the liver be diminished, that of the kidney is increased; and if the secretion of urine be suppressed, the secretion of bile is augmented. When the absorbents are oppressed by the quantity of fluid poured into the stomach, or when the system is at the point of saturation, and no absorption can go on, the veins take up the superfluous liquids, pour them into the circulating current, and bear them to the kidneys, by which organs they are rapidly separated from the blood, and carried out of the body. The weakness of one organ is compensated by the strength of another; the diminished activity of one process is equalised by the increased energy of some other to which it is allied in nature and linked by sympathy; and thus the evils which would result from the partial and temporary failure of an important function are obviated by some vicarious labour, until the enfeebled organ has recovered its tone, and the natural balance of the functions is restored.

The condition acquired by the elementary particles of organised bodies, from their long continuance in the system, which induces the necessity for their excretion, is not known. The chemical elements of the excretions are the very same as those which constitute the organised textures and the nourishment by which they are sustained. Carbon is the basis of the organised body; yet all living bodies, without exception, excrete carbon. Oxygen, hydrogen, and azote, also, without which life cannot be maintained, if retained in the system beyond a given time, are incompatible with the continuance of life. During the chemical changes which these elementary particles undergo, in the course of the vital processes, they appear to enter into some combination, which is no longer compatible with the peculiar mode in which they are disposed in organised and living structures. And one such change, of a very remarkable nature, has been observed, which, it is conceived, has a considerable share in rendering their constant expulsion and renovation indispensable.

Out of the condition of life the component elements of organised bodies readily combine so as to form crystals; the peculiar combinations by which they form the constituent textures of organic structures are never crystalline. No crystal is ever seen in the seat of a living and growing vegetable cellule; no crystal is ever found as a constituent part of animal membrane. Whenever a crystal occurs in an organised body it is always the result either of disease or of some artificial process, or else it is an excretion separated from the nourishing fluid and the useful textures. Every one of these textures contains, even in its minutest parts, saline and earthy, as well as vegetable or animal, matter. Why do not these saline and earthy particles as readily combine to form crystals in the organic as they do in the inorganic body?

They never do. In the organic body these saline and earthy particles are always so arranged that they are diffused through the membranous fibres or cells, never concentrated in crystals.

On the other hand, the elements containing the peculiar matters of excretion are generally in such a state of combination as readily to assume the crystalline form, either alone or in the simplest further combinations of which they are susceptible. It seems probable that this circumstance may be, at least in part, the cause which necessitates their expulsion, and it is certain that some such general principle must determine the incompatibility of the matters of excretion with the life of the structures.

The ultimate object of the processes included in the function of excretion is to maintain the nutritive fluid in a certain chemical condition. Into the combination of the blood there must enter certain constituents, and these must be in certain relative proportions, and in no others. If the salts be diminished or in excess, if the fibrin, or the red particles, or the serum be abundant or defective beyond a certain degree, either the necessary chemical elements are not present, or not present in the form necessary to their entering into the requisite combinations; the result is, that a proper nutritive fluid is not formed, and consequently due nourishment is not afforded to the textures nor due stimulus to the moving powers; there is either too much nutriment and stimulus or too little; in the one case the machine is exhausted and worn out, and in the other it is clogged and stopped.

The capillary arteries of the skin, and of all the other tissues into the composition of which gelatin enters as a constituent, necessarily pour carbon into the capillary veins at the moment they convert albumen into gelatin. The veins, receiving in their course more and more carbon from the arteries, at length become loaded with this element, and in order to get rid of the excess they bear it to the lungs, where it is expelled by the act of expiration under the form of carbonic acid gas. On the other hand the chyle, gradually becoming firmer and more condensed by the series of changes which it undergoes from its first formation in the duodenum to its admixture with the lymph in the receptacle of the chyle, and with the blood in the subclavian vein, is hurried to the heart and thence to the lungs, where it gives off a large portion of its watery particles, also by the act of expiration, under the form of aqueous vapour. This excretion of its watery particles is a necessary part of the process of completion by which the weak albumen of the chyle is converted into the strong albumen of the blood. How completely analogous then is this excretory process in the plant and in the animal! How precisely the same is the action of the leaf and of the lung! The leaf dissipates the superfluous water of the crude sap, concentrates its organic principles, and brings it into the chemical condition which constitutes the proper juice of the plant; the lung removes the superfluous water of the chyle, concentrates its organic principles, and completely assimilates its chemical nature into that of the blood.

It is the same with every other process of excretion; its uniform result is to alter the chemical composition of the nutritive fluid, to restore it to a state of concentration and purity. Excretion, then, is appropriately termed a depurating process.

The effect of the suppression of excretion, when the suppression is complete, is appalling. Stop the respiration, that is, suspend the depurating action of the lungs, carbon accumulates in the venous blood; carbon mixes with the arterial blood; in half a minute the blood flowing in the arteries is evidently darkened; in three-quarters of a minute it is of a dusky hue; in a minute and a half it is quite black; every particle of arterial blood has now disappeared, and the whole mass is become venous. With the first appearance of the dusky hue great disturbance is produced in the system; the instant it becomes dark sensibility is abolished; in a few minutes after it is black the power of the heart is so enfeebled that it can no longer carry on the circulation, and in a few minutes more its action wholly ceases, and can never again be excited. The brain feels the poison first, and is first killed; but the heart cannot long resist the fatal influence.

Stop the excretion of the kidney by the extirpation of the organ, or the suppression of its secretion, urea accumulates in the blood; the poison, after a short time, begins to work; fever is excited, and then, with fearful rapidity, fever is followed by coma, and coma by death.

Stop the secretion of bile, a poison accumulates in the blood as potent, producing insensibility and death as rapidly, as that generated by the suppression of the depurating action of the kidneys.

Only obstruct the secretion of bile, merely prevent its due elimination from the blood, just in proportion to its suppression does the system suffer from languor, lassitude, and inaptitude for every muscular and mental exertion.

How do the internal organs suffer when the excretion of the skin is deficient, and how numberless and hideous are the diseases of the skin when the depurating process of the alimentary canal is suspended!

When, on the contrary, all these excretions are well and duly performed, how regular and tranquil, yet how full and strong the flow of the circulating current; how rich the stream poured by it into every organ; how healthfully exciting its influence on them all; how gentle, how efficient, every organic action; how complete the absence of all note or sensible intimation that any such action is going on, yet how delicious the consciousness produced by its soundness and vigour; how acute the sense, how bounding the motion, how quick the percipience; how pure the blood mantles in the cheek and diffuses its sparkling colour over all the transparent complexion; how the jocund spirits laugh from the eyes; how the intellectual and sympathising mind beams forth from them with a higher and holier happiness! How wonderfully beautiful is such a human body, and how magnificently endowed in its capacity to give and to receive enjoyment!

There are two adjustments, with regard to the excretions, carried on by organised bodies, which can never be contemplated with sufficient admiration. It has been fully shown that the relation established between the two great classes of organised beings is such that the excrementitious matter of the plant is nutritious to the animal, and the excrementitious matter of the animal is nutritious to the plant; and, consequently, that the two orders of living beings maintain the world, which is given them as their inheritance, in a state of perpetual adaptation for the life and health of each other; the animal receiving healthy stimulation from that which is poisonous to the plant, and the plant being nourished by particles which the animal throws off as exhausted and useless. And this relation naturally suggests that so beautifully described by Milton:—

"Flow'rs and their fruit,
Man's nourishment, by gradual scale sublimed
To vital spirits aspire, to animal,
To intellectual; give both life and sense,
Fancy and understanding; whence the soul
Reason receives."

Secondly, the particles thrown off by organised bodies are rendered, in the very act of their dissipation, subservient to purposes of utility and pleasure. How these poisonous elements are converted into the pabulum of life and health has been shown. To a being with the senses and faculties of man, how loathsome might these particles have been rendered during the period of their transition from one organised kingdom to the other! And if disagreeable at all, how constantly forced upon his sense, wherever he might be, during every moment of his waking hours, must these objects of disgust have been! But how does the matter actually stand? The excretions of the plant are the very particles that, poured

"Into the blissful field through groves of myrrh,
And flow'ring odours, cassia, nard, and balm,"

create "a wilderness of sweets." It is as these exhalations are passing off from the economy to which, if retained, they would be noxious, that they become

"Exhalations of all sweets
That float o'er vale and upland:"

and which refresh and delight even more than the forms and colours of the "aery leaf" or "the bright consummate flower."

And the human body, when the functions of its economy are sound and vigorous, is fresh and fragrant as the flower; and by that intellectual faculty by which man is capable of associating his conception of beauty and delight with whatever object has been the source of exquisite gratification, the fragrance of the flower is but suggestive of what, to him, is inexpressibly sweeter and dearer.

"As new waked from soundest sleep,
Soft on the flow'ry herb I found me laid
In balmy sweat, which with his beams the sun
Soon dry'd——
By quick instinctive motion up I sprung,
————And upright
Stood on my feet.———
————All things smiled
With fragrance, and with joy my heart o'erflow'd.
Myself I then perused, and limb by limb
Survey'd, and sometimes went, and sometimes ran,
With supple joints, as lively vigour led."—*Milton.*

——"Fresh lily,
'Tis her breathing that
Perfumes her chamber thus."—*Shakspeare.*

——"The very air
With her sweet presence is impregnate richly,
As in a mead that's fresh with youngest green
Some fragrant shrub exhales——
Ambrosial odours——
Charming present sense,
And sure of memory;—so her person bears
A natural balm—distilling incense."
Death of Marlowe, by R. H. HORNE.

CHAPTER XVIII.

OF NUTRITION.

Composition of the blood—Liquor sanguinis—Recent account of the structure of the red particles—Formation of the red particles in the incubated egg—Primary motion of the blood—Vivifying influence of the red particles—Influence of arterial and venous blood on animal and organic life—Formation of human blood—Course of the new constituents of the blood to the lungs—Space of time required for the complete conversion of chyle into blood after its first transmission through the lungs—Distribution of blood to the capillaries when duly concentrated and purified—Changes wrought upon the blood while it is traversing the capillaries—Evidence of an interchange of particles between the blood and the tissues—Phenomena attending the interchange—Nutrition, what and how distinguished from digestion—How the constituents of the blood escape from the circulation—Designation of the general power to which vital phenomena are referrible—Conjoint influence of the capillaries and absorbents in building up structure—Influence of the organic nerves on the process—Physical agent by which the organic nerves operate.

The object of the greater part of the processes hitherto described is to form the nutritive fluid, and to bring it to the requisite state of purity and strength. Recent researches into the composition of the nutritive fluid confirm the general correctness of the account already given of it.

When examined as it is flowing in the finest vessels of a transparent part of the body, or immediately after it is abstracted from the trunk of a vein or artery, before coagulation takes place, the blood is seen to consist of a colourless fluid, through which is diffused a countless number of minute solid particles of a red colour. The colourless fluid is called the liquor sanguinis, and the solid particles the blood corpuscles or the red particles.

By the process of coagulation, the phenomena of which have been fully described, the blood spontaneously separates into a clear fluid of a yellow colour called serum or blood-water, and into a solid mass termed the clot or the crassamentum. The serum, which must be carefully distinguished from the liquor sanguinis, is the fluid formed from the blood by coagulation; the liquor sanguinis is the fluid part of the blood which exists before coagulation.

The liquor sanguinis contains in solution a large quantity of animal matter, fibrin, which separates spontaneously in a solid form on coagulation; the serum also contains a quantity of animal matter in solution, albumen, which does not separate in a solid form spontaneously, but only on the application of heat, acids, alcohol, &c. The animal matter, the fibrin, which separates spontaneously from the liquor sanguinis in a solid form, constitutes one part of the clot, and the other part of it consists of the red particles which floated in the liquor sanguinis.

Thus, by coagulation, the liquor sanguinis separates into a portion which remains fluid, the serum; and into a portion which becomes solid, the fibrin; while the fibrin, as it is passing from the fluid to the solid state, entangles the red particles, and both together form the clot; consequently the liquor sanguinis contains in solution two kinds of solid matter, fibrin and albumen; while the serum contains in solution only one kind of solid matter, albumen.

The solution of fibrin in the liquor sanguinis, and its spontaneous solidification during the process of coagulation, has been shown by Professor Müller in the following mode. Having carefully collected blood from the femoral artery of the frog, and also from the heart laid bare and incised, and having brought a drop of this pure blood under the microscope, and diluted it with serum, so that the red particles were separated from each other by distant intervals, he observed that there formed in those intervals a coagulation of previously dissolved matter, by which the separated red particles were connected together. By raising, with a needle, the coagulum occupying the intervening spaces, this solid matter was obtained free from red particles. The blood corpuscles of the frog are rendered, by a powerful microscope, so large, that this operation may be performed with the greatest distinctness. In consequence of the minuteness of the red particles of human blood they pass, with the liquor sanguinis, through filtering-paper; but those of the frog, being four times larger, are kept back by the filter, while the liquor sanguinis percolates through as a clear fluid, and then coagulates. This colourless coagulum is so transparent that it is not even detected, after its formation, until it is raised out of the fluid with a needle. It gradually thickens and becomes white. It is the fibrin of the blood in its purest state.

Professor Müller's account of the structure of the red particles differs in a material point from that given. He agrees that they are rounded bodies (Fig. 22), generally of the same size, though some are seen larger than common, but never double the mean diameter; that they are always quite flat; that in a certain light they look as if they were hollowed out from the edges to the centre; but, he adds, "that this spot is a real depression, as some think, appears to me in the highest degree improbable; for I have at last convinced myself that the blood corpuscles of man and the mammalia contain a very small nucleus of the diameter of the flat corpuscle. My observations prove beyond doubt that the blood corpuscles of frogs and salamanders (Fig. 23) contain a nucleus entirely different in its chemical relations from the outer layer. With one of Frauenhofer's microscopes I have seen very distinctly, in the blood corpuscles of man, an exceedingly small, round, well-defined nucleus, yellower and brighter than the transparent circumference. When the blood corpuscles are mixed, under the microscope, with acetic acid, the shell is almost entirely dissolved, and these small nuclei, which are seen with great difficulty in human blood, remain, while those of the frog appear, very evidently the nuclei observed earlier in the blood corpuscles. In man, the nuclei within the corpuscles are so small, that the diameter does not exceed the thickness of the flat corpuscles."

The enveloping capsule is stated to be soluble in water, while the internal nucleus is insoluble; but the capsule is not soluble in serum; the albumen and the salts contained in the serum probably rendering it insoluble. The colouring matter of the capsule, which gives the red colour to the blood, is called hæmatosin. Lecanu considers the capsular substance as a combination of a specific colouring matter, which he calls globulin, and of albumen; but Müller regards it as fibrin, containing a quantity of iron. The latter physiologist states that the opinion of Brande, that the amount of iron in hæmatosin is not greater than in serum and other animal substances, has been refuted by Berzelius and Engelhart. The iron is not an accidental ingredient obtained from the food; for iron has been found in the blood of a new-born animal that has never even sucked. According to Berzelius the colouring matter of the blood contains a quantity of iron corresponding to somewhat more than a half per cent. its weight of metallic iron, and he thinks it most probable that the iron exists in the blood in the metallic state, and not as an oxide.

By carefully watching the development of the chick in the incubated egg, the first formation of the red particles can be distinctly seen. The blood in the new being, which is elaborated before the existence of the vessels that are to contain it, is formed from the substance of the germ, or from that of the germinal membrane, and is augmented by the blood of the egg, which is the substance of the yolk. First, a number of granules are produced from the substance of the yolk. These subsequently lose their granular appearance, and become translucent. On the translucent ring is produced the nucleus of the blood corpuscles. When completely formed, the blood corpuscles of the bird, as of all the animals below the bird in the scale of organisation, are of an elliptical figure, and quite flat; but when first produced they are rounded globules, not flat, and they gradually assume their proper and permanent form; it is only on the sixth day of incubation that they begin to be elliptical; by the ninth day they are all elliptical.

The substance of the fluid yolk is thus changed into blood without the action of any special organ; for, as yet, no organs such as liver, spleen, or lungs, exist. When the formation of the blood has arrived at a certain point, it begins to be in motion. The blood is seen to be in motion before the heart can be observed to beat. The germinal membrane arising out of the enlarged germinal disk soon exhibits a thin upper layer (serous membrane) and a thicker under layer (mucous membrane). There is also formed in the middle of the germinal membrane around the appearing trace of the embryo a translucent space, the *area pellucida.* The exterior of the germinal membrane remains opaque, and this opaque portion becomes divided by a definite boundary into an external and internal annular space in from sixteen to twenty hours. This separation encloses one part of the opaque portion of the germinal membrane, which surrounds the interior or translucent space of the germinal membrane, and is termed *area vasculosa,* because the blood and vessels form the inner half of this space.

As far as the area vasculosa extends, a granular layer is presented between the two layers of the germinal membrane, which soon divides into numerous granular isolated particles with translucent intervals, in which the blood collects, first in the form of a yellowish, and then of a reddish fluid; first distinctly in the periphery of the area vasculosa, from which it is seen to flow towards the heart before the heart beats.

The blood exerts its vivifying influence chiefly by the red particles. If an animal be bled to fainting, and pure serum be injected into its vessels, reanimation does not take place; but if the blood of another animal of the same species be injected, the animal which was apparently dead acquires new life at every stroke.

The fibrin may be removed from the blood without injuring the red particles. If the fibrin be abstracted, and a mixture of the red particles and the serum be brought to a proper temperature, and injected into the veins of an animal bled to fainting, reanimation is effected.

If the blood of an animal of another species be injected whose red particles are of the same form, but of a different size, reanimation is indeed effected, but the restoration is imperfect; the organic functions are oppressed and languish, and death takes place generally within the sixth day. The same effects follow, if a mixture of serum and red particles of the blood of a different species be injected.

If blood with circular particles be injected into the vessels of an animal whose blood corpuscles are elliptical, the most violent effects are instantly produced; such blood acts upon the nervous system like the strongest poisons; and death usually follows with extreme rapidity after the injection of a very small quantity. Thus, if a few drops of the blood of the sheep be injected into the vessels of the bird, the bird is killed instantaneously. It is very remarkable, that the blood of the mammalia should be thus fatal to the bird. The effect cannot be dependent on any mechanical principle. The injection of a fluid with particles the diameter of which is greater than that of the capillary blood-vessels would of course destroy life by stopping the circulation; but the blood corpuscles of the mammalia are much smaller than those of the bird; yet the pigeon is killed by a few drops of mammiferous blood; and the blood of the fish is rapidly fatal to all the mammalia as well as to birds.

It is manifest, both from observation and experiment, that arterial blood is far more necessary to the support of the animal than of the organic life. When in asphyxia the communication of atmospheric air with the lungs is suspended, the functions of the brain are abolished; sensibility and voluntary motion are lost the moment venous blood circulates in the arteries of the brain. It has been shown, that if this state continue, the animal life is destroyed in a minute and a half; but that the organic life is not extinguished for many minutes, and sometimes not even for several hours.

It sometimes happens that the communication between the pulmonary artery and the aorta, and between the right and left auricle, which naturally exists in the fœtus, is continued after birth. In persons having this state of the circulation, called ceruleans, some portion of venous blood is always mixed with arterial blood. In this case the various processes of secretion and nutrition, the entire circle of organic functions, are but little disturbed; while the animal functions are deranged in a remarkable degree. The mind is weak and inactive, and the muscular power is so feeble, that the least exertion produces a sense of suffocation; and, if the muscular effort be continued, occasions fainting, and even suspended animation.

But while venous blood is in no case capable of supporting sensation and voluntary motion, there are decided cases in which secretion is effected, at least in part, from venous blood, as the bile from the venous blood that circulates through the liver in man and all the mammalia, and the urine which is formed from venous blood in some of the lower orders of animals.

The proper nutritive fluid of the human body is directly formed from chyle, lymph, and venous blood; that is, partly from new matter introduced into the system from the external world, and partly from matter which has already formed a constituent part of the body. The new matter, the white chyle, is prepared partly by the action of the digestive fluids upon the food, and partly by the addition to the digested food of highly animalised substances, endowed with assimilative properties, by which the product is progressively approximated to the chemical composition of the blood. The old matter consists partly of the clear lymph, contained in the lymph-vessels, and derived from the interior of the organised parts, particles which have already formed an integrant portion of the tissues and organs; and partly of the dark venous blood, the residue of the proper nutritive fluid, after the latter has yielded to the system the new matter required by it, and has given off from the system its superfluous and noxious particles.

In the duodenum and jejunum the new matter, the chyle, contains albumen; but it is without coagulable fibrin: it acquires fibrin in the lymph vessels on its way to the veins.

In the chyle globules appear; but the chyle corpuscles are white, are without an external envelope, are comparatively few in number, are somewhat more than half the size of the blood corpuscles, and, like the nuclei of the latter, are insoluble in water.

The fatty or oleaginous matter contained in the chyle is in a free state, not intimately combined.

The chyle is alkaline, but is much less alkaline than the blood; and the iron contained in the chyle is much less intimately combined than it is in the blood.

Lymph contains in solution more animal matter than chyle, and the white globules are more abundant in lymph. But though lymph contain in solution more albumen and fibrin than chyle, it is not so richly loaded with these substances as blood. Still, however, the solution of albumen and fibrin in lymph approximates lymph so closely to the blood, that the lymph very much resembles the clear liquor sanguinis of which the blood consists when the red particles are abstracted from it. The colourless liquor sanguinis is the lymph of the blood. Lymph is blood without red particles; and blood, lymph with red particles.

The chyle is transmitted into the lymph-vessels to mingle with the lymph before it flows into the veins to mingle with the blood.

The commingled fluids, chyle and lymph, pass into the blood very slowly, drop by drop. The regulation of the rapidity of the admixture seems to be the chief office of the valve placed at the termination of the thoracic duct. When the operation is observed in a living animal, it is seen that this valve prevents the new matter from flowing into the blood in a full stream. If in a dog of ordinary size that has recently eaten as much animal food as it chose, the thoracic duct be opened in the neck, the dog being alive, there will flow from the duct about half an ounce of fluid in five minutes; yet when this fluid reaches the termination of the duct only a few inches further on, it flows into the vein only drop by drop, at considerable intervals. One great object of pouring the chyle and lymph into the venous system so close to the heart (Fig. 91), and of causing the commingled fluid to pass under the action of that powerful engine before it is transmitted to the lungs, seems to be, by the agitation to which it is subjected in the right auricle and ventricle to accomplish the most perfect admixture possible between the particles of the chyle and lymph and the red particles of the venous blood; an object which would be counteracted by the too rapid entrance into the current of the circulation of the new and as yet imperfectly assimilated matter.

After their due admixture by the powerful action of the engine that works the circulation, the commingled fluids are transmitted by the right heart to the lungs. There the watery portion of the chyle and lymph is removed; the composition of the albumen and fibrin is completed, these substances being changed from a weak and loose into a strong and concentrated state; the solid particles are increased in number, augmented in size, and changed from a white into a red colour; carbon is given off; oxygen is absorbed; azote is alternately inhaled and exhaled; and the ultimate result is, that the three fluids—chyle, lymph, and venous blood—are converted into one homogeneous fluid, arterial blood, the proper nutrient fluid.

The particles of the chyle and lymph, on mingling with the blood, are scattered through the mass, and become invisible, being apparently lost among the innumerable red corpuscles; but it is not probable that the chyle is immediately converted into blood. If the coagulation of the blood be retarded by the addition of a small portion of the carbonate of potass, the red particles gradually sink some lines below the level of the fluid; and the supernatant liquid is whitish, evidently from the chylous globules mingled with the blood. In ordinary coagulation, the chyle globules are included among the immense number of the red particles of the coagulum, and are thus indistinguishable; but there is reason to believe that the chyle is not converted into blood under at least from ten to twelve hours: it is certain, that in that space of time after the completion of digestion, the serum of the blood is frequently seen to be milk-white, from the quantity of unassimilated chyle still contained in it.

How the red colour of the blood is obtained, and whence the capsules of the red particles are derived, if these bodies really possess an external envelope, is wholly unknown. But it has been shown that in incubation the blood is formed from the substance of the fluid yolk, without the action of any special organ; that at the period when the blood is first generated, no such organs as appear to influence the production of the blood in the adult are in existence; it is, therefore, reasonable to infer that the formation of blood in the adult may not be so dependent on the action of special organs as is commonly supposed; and that the formation of blood from chyle, of blood corpuscles from chyle corpuscles, may take place at all periods of life under the influence of the same general vital conditions as it does in the incubated egg.

What change the matter of the blood undergoes by respiration, whether it acquire something without which it is incapable of maintaining life, or part with something the presence of which is incompatible with life, is equally unknown. We only know that the blood, during respiration, changes its colour; but of the nature of the change produced upon its substance we are wholly ignorant. In the present state of our knowledge, the ultimate fact is, that without the change wrought upon the blood by respiration, the blood is incapable of maintaining life; in fact, no proper nutrient fluid is formed.

Once formed, the conservation of the proper proportions of the composition of the blood is effected by the excretory processes already described; by the removal of its superfluous water by the lungs, skin, and kidneys; by the removal of its superfluous carbon, azote, and oxygen by the lungs, liver, and kidneys; by the removal of saline and mineral matters chiefly by the kidneys; and finally by the instantaneous removal of products of decomposition formed in the course of the organic actions, chiefly, it would appear, by the kidneys.

Once formed, and duly concentrated and purified, the blood is sent out by the left heart to the system. Driven by the heart through the main trunks and branches of the aorta, the blood ultimately reaches the capillary arteries, which do not divide and subdivide indefinitely, but ultimately reach a point beyond which they no longer diminish in size. Not all of the same magnitude, some are large enough to admit of three or four of the red particles of the blood abreast; the diameter of others is only sufficient to admit of two or even of one; others are capable of transmitting only the clear and transparent liquor sanguinis; while in many cases the membranous tunics of the capillaries wholly disappear; the blood no longer flows in actual vessels, but is contained in the substance of the tissues in channels which it forms in them for itself.

Under the microscope, says Professor Müller, the blood corpuscles are seen distinctly pouring from the smallest ramifying arteries into vessels which grow no smaller. After leaving these, they again assemble in the origins of veins formed in collected branches. The blood corpuscles flow in the finest capillaries, one after another, and often interruptedly. They are colourless when they flow singly; accumulated more thickly, they appear yellow, and in still greater quantity, yellowish-red or red. In animals that have lost their strength, the globules flow without stoppage: when the animal is weak and the motion is retarded, the globules move by starts; they move on, but go more rapidly by fits. In a still weaker animal they only advance during the impulse of the heart, and then fall back a little. When several arterial currents unite in an anastomosis, one current always predominates and traverses the anastomosis alone, to mingle its blood in the other currents. Thus the currents meet and divide in the reticulate capillaries till all are collected again in veins. Sometimes the direction of the current changes, when another current becomes stronger, and the previous leader weaker, according to the pressure exerted on the part.

While the blood is thus traversing the capillaries, its colour changes from a bright scarlet to a dark red. This change in the colour of the blood is the certain sign that particles have been abstracted from the circulating mass, and have been applied to the formation and support of the fluid and solid parts through which the stream is flowing. Some physiologists have satisfied themselves that they have seen the actual escape of particles from the circulating current; that they have witnessed the immediate combination of those particles with the substance of the tissues, and even that they have beheld other particles quitting the tissues and mingling with the flowing blood. Other physiologists doubt whether the most patient observation, aided by the most skilful management of the best glasses, can ever have rendered such phenomena matters of sense. "I imagined," says Müller, "at an early period, that I had seen something like this in the setting circulation; but by prolonging the observation I saw the globules move on if the current continued."

But whether the human eye have ever actually seen or not an interchange of particles between the blood and the tissues, it is absolutely certain that such an interchange does take place. For,—

1. Indubitable evidence has been stated of continual absorption from all parts of the body, yet there is no loss of substance; there must, therefore, of necessity be a proportionate deposition.

2. Equal evidence has been adduced that constant additions are made to the blood through the organs of digestion, yet the quantity of the blood in the body does not progressively and permanently increase; it follows that a quantity must be abstracted from the blood proportionate to the quantity added to it.

3. The human germ, from a scarcely visible point, by the successive additions of new matter progressively acquires the bulk of the adult man.

4. Organs whose special office it is to abstract particles from the blood for the elaboration of specific secretions consist almost entirely of congeries of blood-vessels. The agents are multiplied in proportion to the extent of the labour assigned them.

5. Growth, which is merely excess of deposition above absorption, is active in proportion to the quantity of blood which circulates through the growing part in a given time. The blood-vessels of a growing part increase in number and augment in size in proportion to the rapidity of the growth. In morbid growth, it is sometimes sufficient to stop the process merely to tie the main trunks of the arteries distributed to the part.

By every organ and every tissue; by the membrane, the muscle, the bone; by the brain, the heart, the liver, the lungs, particles are abstracted from the countless streams that bathe them, or that flow through them. In every case in which particles are thus abstracted by a tissue the following phenomena take place:—

1. Only those constituents of the blood are abstracted by the tissue which are of the same chemical nature as its own.

2. The constituents of the blood abstracted by a tissue, identical in chemical composition with its own, are immediately incorporated into its substance.

3. The constituents of the blood abstracted by a tissue, as they are incorporated into its substance, are not disposed fortuitously, but are arranged according to the specific organisation of the tissue, and thus receive its own peculiar structure.

4. The constituents of the blood which thus receive the peculiar organisation and structure of the tissue by which they are appropriated, acquire all its peculiar vital endowments.

It is manifest, then, that the tissues assimilate the blood just as the digestive fluids assimilate the aliment. And this is nutrition, the assimilation of the blood by the tissues and organs. Digestion is the conversion of the food into blood; nutrition is the conversion of blood into living fluids and solids.

For the reasons assigned, it is probable that the living fluids and solids, formed from the blood by the act of nutrition, are not generated at the parts of the body where they appear, but that, pre-existing in the blood, they are merely evolved at those parts. Hence the variety and complexity of the processes for the elaboration of the blood which have been described, and all of which appear to be indispensable to bring the blood to a proper state of purity and strength. The great effort of the system is put forth in effecting the constitution of the blood. When the blood is once formed, all the rest of the work appears to be easy; because, before it reaches any part of the organisation which it is destined to support, the blood is already adapted, mechanically, chemically, and vitally, to afford that support. Still since there are cases, as in the production of gelatin, in which the substance does not appear to be pre-existent in the blood, we are under the necessity of supposing that a material change is effected in the constituents of the vital fluid at the time and place of their escape from the circulation.

How the constituents of the blood escape from the circulation and incorporate themselves with the substance of the tissues there can be no difficulty in conceiving, wherever the capillaries terminate in membraneless canals, channels worked out for the reception of the nutrient stream by the force of the current itself; and in every case in which the capillaries, retaining their membranous tunics, remain true and proper vessels, their contents escape through their delicate walls by the process of endosmose, for which their structure appears to be admirably adapted.

But in the capillary vessels there exists only blood. Universally and invariably before the blood passes from under the influence of the capillary vessels it has ceased to be blood. Arterial blood is conveyed by the carotid artery to the brain; but the cerebral arteries do not deposit blood, but brain. Arterial blood is conveyed by the capillary arteries to bone; but the osseous capillaries do not deposit blood, but bone. Arterial blood is conveyed by the muscular arteries to muscle, but the muscular capillaries do not deposit blood, but muscle. The blood conveyed by the capillaries of brain, bone, and muscle is the same; all comes alike from the systemic heart, and is alike conveyed to all tissues; yet in the one it becomes brain, in the other bone, and in the third muscle. Out of one and the same fluid are manufactured cuticle, and membrane, and muscle, and brain, and bone; the tears, the wax, the fat, the saliva, the gastric juice, the milk, the bile, all the fluids, and all the solids of the body.

These phenomena are wholly inexplicable on any known mechanical principles. It is equally impossible to refer them to mere chemical agency, or to any properties of dead matter. We are, therefore, under the necessity of referring them to a principle which, for the sake of distinguishing it from anything mechanical or chemical, we term vital. As the actions which take place between the integrant particles of bodies, giving rise to chemical phenomena, are referred to one general principle, termed chemical affinity, so the actions which take place in living bodies, giving rise to vital phenomena, may be referred to one general principle, termed vital affinity. The term explains nothing, it is true, it merely expresses the general fact; but still it is convenient to have a term for the expression of the fact. The property itself will ever remain an ultimate fact in physiology, however exactly the limits of its agency, and the laws according to which it modifies the mechanical and chemical relations of the substances subjected to its influence, may hereafter be ascertained; just as chemical affinity will ever be an ultimate fact in physics, whatever discoveries may yet be made of the extent of its agency and of the conditions on which its action depends.

It is then an ascertained fact, that there exists between the blood and the tissues a mutual reaction, not of a physical, but of a vital nature, in which the blood takes as active a part as the tissue, and the tissue as the blood; the blood exerting a vital attraction on the tissue, and the tissue on the blood. We only express this ultimate fact when we say (and this is all we can do) that in every part of the body, by virtue of a vital affinity, the tissue attracts from the blood the molecules of matter appropriate to its chemical composition, and the blood attracts from the tissue the particles which, having served their purpose there, are destined to other uses in the economy; or, if wholly useless, are absorbed into the current of the circulation to be expelled from the system.

We can see how the particles of matter which are attracted by the tissue from the blood are so deposited and disposed that the tissue always preserves its own shape, bulk, and relation to the surrounding tissues. This definite arrangement is the result of an action which has been already stated to be proper to the absorbent vessels. Previously to the deposition of a new particle of matter by a capillary, an old particle is removed by an absorbent, either a lymphatic or a vein. In removing the old matter, the absorbent forms a mould into which the capillary deposits the new molecules; and the form of every tissue and organ depends on the kind of mould formed for the reception of its nutrient matter by the absorbent vessel. The absorbents are thus the architects of the system; and the capillaries are both chemists which form the rough material employed in the structure, and masons which deposit and arrange it. The conjoint action of both sets of vessels is necessary to the formation of the simplest tissue; and it is by their united labour that the compound organs are built up out of the simple tissues.

It is conjectured that the immediate living agents by which this vital attraction is exerted between the blood and the tissues are the organic nerves. These nerves consist of two sets, those which enter as constituents into the tissues and those which accompany the capillaries. It has been shown that while the membranous tunics of the capillaries diminish, the nervous filaments distributed to them increase; that the smaller and thinner the capillaries the greater the proportionate quantity of their nervous matter; and that this is most remarkably the case in organs of the greatest irritability. It is conceived that the capillaries, in consequence of the nervous structure which thus envelops them, exert upon the fluid which is flowing through them an influence perfectly analogous to that of the secreting organ, in consequence of which similar particles are abstracted from the blood as those which compose the tissue in which the operation takes place.

It is further conjectured that the physical agent by which this action upon the blood is effected is the galvanic fluid. Dutrochet believes that he has actually formed muscular fibre from albumen by galvanism. He considers the red particles of the blood as pairs of electrical plates, and thinks that the nucleus is electro-negative, and the capsule electro-positive. Müller has repeated and critically examined the interesting experiments of Dutrochet; and while he arrives in many essential points at different results, expresses the highest admiration of the ingenious manner in which this philosopher has sought to solve a great problem. "If," says Müller, "a drop of an aqueous solution of the yolk of egg (in which very small microscopic globules are suspended) be galvanised, the currents discovered by Dutrochet will be observed. The wave, proceeding from the copper or negative pole, in which the alkali of the decomposed salt accumulates, is transparent, from the solution of albumen by the alkali. The wave proceeding from the positive or zinc pole, particularly in its circumference, is opaque, and white from the acid it contains. Both waves encounter, and exactly in the line of contact a linear coagulum is immediately produced, which assumes the form of the line of contact, and is curled at times as the edges of the waves are meeting. The meeting of both waves takes place with a lively motion, in the line of contact, when the deposition of coagulum takes place; but as soon as the deposition of coagulum has occurred, all is tranquil, and not the least trace of motion is observed. It is therefore inconceivable how an observer of the first rank, like Dutrochet, can pronounce this coagulated albumen to be contractile muscular fibre, generated by galvanism; it is nothing but coagulated albumen. This coagulum, besides, like the albumen which is deposited by galvanism round the zinc pole, has no consistence, but is composed of globules easily separated by stirring, and only precipitated in the line where the two waves meet without cohesion."

But though science has not yet succeeded in ascertaining with certainty the physical agency to which the ultimate changes that take place in organised matter are to be referred, there cannot be a question that they are dependent on physical agents; and the legitimate object of scientific inquiry is to discover what those agents are, and to ascertain the modifications they undergo by those vital affinities to the influence of which they are subjected.

The discoveries which science has already made relative to the influence of certain physical agents on particular organs, and to the influence of the whole circle of physical agents on the whole living economy, have added not a little to human power over human health and disease. But these agents also exert an influence scarcely less momentous on the entire apparatus and action of the animal life, so inseparably linked with the organic. An account will therefore be next given of the structure and function of the nervous and muscular systems.

CHAPTER XIX.

NERVOUS SYSTEM.

Definition of the term nervous system—Constitution of nervous substance—Functions of nervous substance—Action of stimuli.

The nervous system comprehends nervous substance, nerves, and nervous centres. The name given to this system—from νευρον, *nervus, nerve*—appears to have been derived originally from a Greek word, signifying to extend; because nerves were conceived to be prolongations of the medullary substance of the brain. The term nerve, in its restricted sense, signifies the cord of nervous matter which is commonly known under that name; used adjectively, *nervous*, it has a more comprehensive use, and is applied to the whole system.

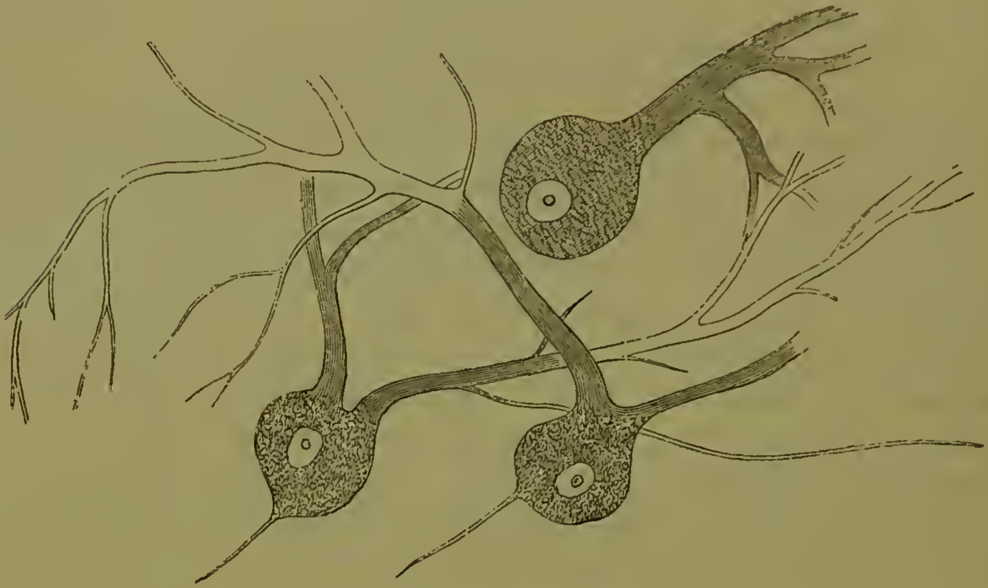
Nervous Substance.—Nervous substance constitutes a distinct form of organic matter, often called neurine. It is quite peculiar in its chemical composition, structure, and endowments. Its existence is limited to the animal organism. No trace of it is found in the vegetable kingdom; nor has it been found in the lowest forms of animal life. It is the only known form of matter which stands in direct relation to the mind; the only one on which the mind directly acts, and through which it is acted upon.

The basis of nervous substance is the proximate principle albumen. It is a proteine compound, united with a peculiar fatty matter, which, unlike other oleaginous substances, contains nitrogen, and some fatty acids, as the cerebric and oleophosphoric. In 100 parts, 7 consist of albumen, 5 of fatty matter, and 80 of water; the remaining 8 being made up of osmazome, phosphorus, sulphur, and salts. Regarded chemically, therefore, nervous substance is an emulsive admixture of albumen, fatty matter, and water, intimately combined with a small proportion of certain incidental, that is, saline and mineral elements.

It consists of two forms of matter, chemically and anatomically different from each other; one being of a grey, the other of a white colour. The grey matter differs chemically from the white, in containing more albumen and water and less fat, the white consisting of so large a proportion of fat as to derive from it its white colour.

Anatomically, the grey substance consists of very fine molecular matter, in which are embedded delicate transparent vesicles, termed nerve-vesicles or corpuscles. They are all essentially nucleated cells (Fig. 100). They vary in size from the $\frac{1}{1250}$ to the $\frac{1}{300}$ of an inch, and contain, within their delicate membranous walls, extremely fine granular matter, similar in appearance to the molecular particles in which they are embedded. Larger particles of a darker colour, collected into groups, are here and there intermixed with them, and are called pigmental particles (Fig. 100). The nerve-vesicles, like nucleated

Fig. 100.



Large cells of the grey layer of the cortical substance of the human cerebellum. Magnified 350 times.

cells, in general contain a nucleus and nucleolus (Fig.100). Most of them are simple spherical cells, but many present offshoots, or processes, called caudate or tail-like processes (Fig. 100). A single vesicle may produce one or several of these elongations, and, according to the number they send off, they are termed uni-, bi-, or multi-polar vesicles (Fig. 100).

This form of nervous substance abounds in all the nervous centres, and also, as has been lately discovered, in the peripheral expansions of some of the nerves of sense, as in the retina, and at the terminations of the olfactory and auditory nerves.

On the other hand, the white substance, to the naked eye, looks perfectly homogeneous and structureless, something like a slice of cream-cheese. It is, however, really made up of an assemblage of minute threads or fibres (Fig. 100), and this fibrous structure forms its essential character.

There are, then, two elementary forms of nervous matter, one consisting of molecular substance and of vesicles, and the other of threads or fibres; the first being appropriately called vesicular and the other fibrous, as indicating their more obvious forms. These two substances, variously arranged and combined, form the several organs of the system.

The really dynamic part of nervous substance is the molecular grey matter; the vesicles are subordinate, mainly retentive, and probably formative bodies, secreting, so to say, the granular matter.

Functions of Nervous Substance.—Nervous substance is the seat and source of a peculiar force, as distinct from every other as that of attraction or electricity. It is termed nervous force. It is inherent in nervous matter. The minutest particle develops it as completely as the largest mass, only not in so great a degree. It is built up into complex organs in order to accumulate, concentrate, and modify in many important respects, the distribution and action of the force, but the force itself resides in the ultimate organic particles or atoms, altogether beyond the reach of the most powerful microscope.

Nervous force is strictly limited to the animal body. No trace of it exists in the vegetable kingdom. Even in the animal body, nervous force is definitely limited to the structures and actions of the animal life. All the vegetative or organic processes, which the animal performs in common with the plant, are carried on without any direct influence of the nervous system, the entire apparatus of which is strictly devoted to the communication and maintenance of the two great endowments which are superadded to the animal—sensation and motion. This, among many other proofs, is indicated by the anatomical fact, that on arriving at the real agent of an organic process, even in the animal body—as the air-cells, the hepatic cells, and so on—no nerve-fibres are to be found: they stop short at the point where the muscular part ends, as is seen in the bronchi, the hepatic ducts, &c.

All nervous force is generated in nervous centres, which are, therefore, called dynamic: these are the ganglia, the spinal cord, the medulla oblongata, and the brain.

Of the two forms of substance that compose the nervous centres the grey matter is the dynamic part. The following considerations afford conclusive evidence of this:—

1. Grey matter is found in all active centres in proportion to the range and energy of their action.

2. It is on grey matter exclusively that impressions are received, whether when the mind acts upon the brain, as in volition, or whether when physical stimuli act on the peripheral expansions of the nerves of sense, in the communication of impressions to the mind, as when light falls on the retina, and the pulsations of air excite the organ of hearing.

3. Grey matter, in the animal series, is added or subtracted according to the presence or absence of an active organ of sensation or motion. The evidence from comparative anatomy in proof of this is decisive.

In the oyster, for example, there is no foot, and no pedal ganglion;

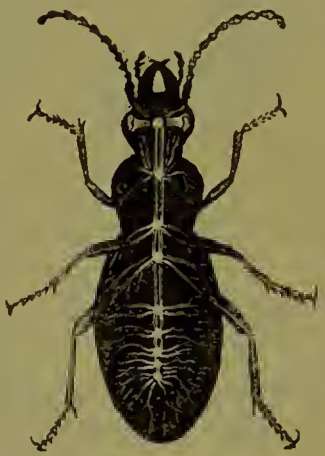
but when a foot appears, as in the scallop (Pecten), then a new ganglion, the pedal, is added.

The common earth-worm moves by a series of motor rings, to each of which a ganglion is appropriated.

In the Julus terrestris there are 92 pairs of legs and 92 ganglia. In another genus (Chyoni bregmatus) there are no fewer than 160 legs, and these are supplied by 160 ganglia.

In insects which undergo metamorphosis, as the butterfly, moth, and so on, there are in their rudimentary state—that is, in the state of larva—13 motor segments, and here there are 13 ganglia. But in the process of metamorphosis the prolegs and some other parts disappear or are thrown off, and their ganglia either coalesce or are absorbed. When the insect acquires its full perfection, its nervous system is concentrated, in accordance with a general law, and in the imago there are only 9 ganglia.

Fig. 101.



Nervous system of an insect (Carabus of the gardens). A beetle.

Wherever there are eyes there are optic ganglia; in creatures without eyes there are no such ganglia.

In the higher animals the size of the ganglia which supply the sensory apparatus is proportionate to the acuteness of the senses, as is seen in the large size of the olfactory ganglia in animals distinguished for the acuteness of their smell, and in the optic ganglia in those which possess the most perfect vision. The intellectual faculties are developed, as their instrument, the grey matter of the brain, is accumulated and concentrated. The enormous bulk of the convolutions of the human brain, which consist almost entirely of grey matter, distinguishes it from the brain of the lower animals more than its comparative size.

The comparatively small quantity of grey matter in the human brain at birth, as contrasted with the vast mass of it which is developed at mature age, is also very remarkable In the new-born infant the convolutions are only in a very early stage of their formation: they are merely mapped out by superficial fissures almost confined to the surface of the brain. At this time the relative proportion of grey matter in the spinal cord is much larger than it is in the brain. At this period the functions of the true spinal cord are in full activity, building up and developing the structures of the body, while the true intellectual faculties are only just beginning to indicate their existence. As these latter progressively increase, and at last predominate over the former, the quantity of grey matter in the two centres is reversed; that in the spinal cord proportionally diminishes, that in the brain increases enormously.

4. The quantity of arterial blood with which the grey matter is supplied is a further confirmation of its relative importance. An invariable test of the activity and energy of an organ is afforded by the quantity of arterial blood which is sent to it. The grey matter is so much more abundantly supplied with arterial blood than the white, that in minute injections of the cerebral substance the grey becomes pink, while the white is only slightly tinged.

5. The white or fibrous matter of the nervous centres constitutes, on the other hand, an apparatus of conduction. When nervous force is generated in the grey matter, there must be some means of carrying it out to the different parts of the body. This is the office assigned to the white matter, the fibres of which are merely carriers, analogous in this respect to the electric wires.

6. All the nervous centres are independent of each other. The ganglionic centre is independent of the spinal cord, and both are independent of the brain. Each has its own definite and strictly limited office to perform, which it cannot give to another, and which cannot be supplied by another.

7. Yet they all mutually and most powerfully influence each other. They are placed in the closest union, and special, one might almost say anxious, provisions are made to cause them to work together, which they do in harmony so complete that the due action of one contributes to that of all the others, and one cannot suffer without a corresponding disturbance of the rest.

8. Nervous force cannot be developed without the presence of a stimulus. Some agent capable of making an impression upon, that is, exciting the powers of the nerve-fibres, must be in contact with them. These fibres are charged with force, but it is not set in action until stimuli are applied. I will to move my arm. My volition is a stimulus, which, exciting the brain to action, causes it to send out by the volitional fibres a nervous force which they transmit to the voluntary muscles, on the reception of which these muscles are instantly roused

to simultaneous and combined contractions, by which the required motions are produced.

A ray of light falls upon the peripheral expansion of the optic nerve, the retina. The ray of light is a stimulus, which, being transmitted by the sensory fibres to the brain, produces a change in its state of consciousness; produces, that is, an impression, and this is followed by a perception, in this case a perception of light.

I press the point of my finger on the table. The sensory fibres of the skin, receiving this mechanical stimulus, transmit it to the brain, where it produces another impression, which is followed by a new perception, that of touch.

The different kinds and action of stimuli will be considered hereafter, when we treat of the properties of nerves. What has now been stated may suffice to convey a conception of the properties and powers inherent in nervous matter in general. But this matter is built up into structures, more or less complex, forming organs, or a series of organs combined into an apparatus. The simplest of these organs is a nerve, the structure and functions of which are next to be stated.

CHAPTER XX.

STRUCTURE OF NERVES.

Constituents of nerves—Structure of compound fibres—Primitive fibres—Disposition and relation of fibres to each other—Origin and termination of fibres—How fibres possessing different properties are bound up in the same trunk—Ultimate termination of fibres.

A NERVE is a cord-like substance connected by one extremity with a nervous centre, and by the other with an organ or tissue. To the naked eye it is seen to consist of a number of fibres enveloped in a common membranous sheath.

When examined further by the microscope it is found that each of the coarse fibres visible to the naked eye is in reality composed of a multitude of extremely delicate threads, the primitive fibres, each consisting of soft, pulpy neurine, enclosed in a tube of membrane, called from its minuteness a tubule. The membrane that forms the tubule is termed *neurilemma*, from *νευρον*, *nerve*, and *λεμμα*, *bark* or *tegument; nerve bark or tegument,* because it encloses the nervous matter, as the bark encloses the trunk and branches of a tree. It is estimated that it is not more than the twenty-thousandth part of an inch in thickness; yet it possesses considerable firmness. Under the microscope its presence is indicated by a fine dark line bounding the tubule, and when the neurine is squeezed out of it, it is seen as a distinct tube. It sustains and protects the nervous substance, and transmits to it nutrient matter through its porous walls.

Immediately under the neurilemma there is a layer of whitish material, which gives to the fibre its white colour, and which is called, after the physiologist who first described it, *the white matter of Schwann.* Within this, again, occupying the very centre of the tubule, there is a transparent, flattened band of a grey colour, and extremely delicate, directly continuous with a caudate vesicle (Fig. 100). This is termed the *central axis*, or the *axis cylinder.* It is the essential part of the organ. The perfect distinctness of these two substances, a fact of prime import in the physiology, can be proved by chemical tests and other means.

A primary nerve-fibre, then, is composed of an external membranous sheath, a layer of white matter immediately within the sheath, and an inner central axis of grey substance.

Fibres thus organised are associated together in vast numbers, bound up in cellular tissue, collected into packets, supplied with blood-vessels and absorbents, and the whole are enveloped in a common fibrous membrane or general sheath. The result of the union of all these parts taken together is the organ termed a nerve.

The primitive fibres differ considerably in size, not only in different animals, but in different parts of the same animal. They are largest in the lowest animals. In fishes they vary from the $\frac{1}{1600}$th to the $\frac{1}{2000}$th of an inch; in reptiles, from the $\frac{1}{2000}$th to the $\frac{1}{1200}$th; in birds, from the $\frac{1}{3000}$th to the $\frac{1}{2000}$th; in man, from the $\frac{1}{12000}$th to the $\frac{1}{1500}$th of an inch.

The smaller the fibres, and the greater their number, the larger is the amount of nervous substance in a given mass.

The primitive nerve-fibres lie side by side within their common sheath, close to, and parallel with each other; they are simply in apposition; they never unite; they never fuse into each other's substance; they are in contact only by the external surface of their neurilemma, and they keep perfectly distinct in their entire course.

Every primitive fibre is also uninterruptedly continuous from its origin to its termination.

That extremity of a nerve which is in connection with its nervous centre is called its origin, or central extremity—centrifugal; that which is distributed to a tissue or organ is named its termination, or its peripheral extremity—centripetal.

At its origin every nerve, by its primitive fibres, is in communication with grey matter, apparently in two modes. First, as just stated, some fibres are, by their central axes, processes or prolongations of caudate vesicles. (Fig. 100.) Secondly, many fibres twine between and around the simple spherical nerve-vesicles, thus greatly increasing the extent of contact between the two elements. The white matter of the primitive fibres, however, stops at the external surface of the vesicles, and never penetrates their membranous wall, or passes into their interior.

At its peripheral extremity, the main trunk of a nerve, as it approaches the tissues and organs to which it is to be distributed, is seen to break up into a number of branches, which commonly plunge directly into the tissues and organs, dividing and subdividing as they proceed. At other times, while the main divisions of a parent trunk proceed in a direct course to the peripheral organs, a certain number of the branches connect themselves with branches from other nerves, unite with them, follow their course, and completely abandon their primary trunk; so that fibres possessing widely different, and even opposite properties, which they retain after the union, become bound up together in the same common trunk. The trunks themselves, as those of the arms, sometimes unite together, and thus form a complex network, termed a plexus.

With respect to the individual nerve-fibres, it is supposed that they commonly terminate by single points. Sometimes, however, they form loops, and this looped termination has been recently proved to be more general than was formerly supposed. Recent researches have led to the observation of still another mode of termination. Mr. Bowman has shown that on carefully tracing, under a high magnifying power, a fibre supplying an organ of sense, a papilla of the tongue, for example, the white matter, after going some way towards the papilla, suddenly stops, while the central axis proceeds onwards alone, and terminates at the very point of the papilla.

The same remarkable fact is observed in certain bodies first described by an Italian anatomist, Pacini, and called, after him, the Pacinian corpuscles. These are minute granules of nervous matter, attached by small pedicles or footstalks to certain nerves, especially those of touch in the hand and foot; more sparingly to other spinal nerves; and found also in the plexuses of the sympathetic nerve: but in all cases, even in the latter, these bodies are exclusively restricted to the white tubular nerves. Each corpuscle appears to the naked eye as a small, oval, pellucid grain, but when viewed by the microscope, one of the most complex and remarkable structures of the whole nervous system is revealed. Each body so seen consists of about sixty or more concentric capsules, or laminæ, enclosed one within the other, separated from each other by minute septa, and containing between them a transparent liquid. To the pedicle of each corpuscle a primary white nerve-fibre is attached: this penetrates all the capsules, and so reaches the central cavity, where it lays aside the white matter of Schwann, whilst the grey axis cylinder runs in a straight direction through this cavity, till, arriving at its more remote part, the grey axis becomes fixed to the most internal capsule. These bodies are well supplied with blood, and, in their minute disposition of capsules and septa, strikingly resemble the electric apparatus of the torpedo, as Pacini himself suggested.

CHAPTER XXI.

FUNCTIONS OF NERVES.

Grey matter is the source of nervous force; nerves are the conductors of it. For the office of conduction two conditions are necessary in the instrument—uninterrupted continuity and insulation. The anatomical structure of a nerve fitting it for the accomplishment of these objects, was first demonstrated by Sir Charles Bell, the great founder of scientific neurology, who has so clearly expressed the facts and exhibited the clue to the physiology, that it would be an injustice to the subject to use any language but his own.

After describing a nerve enveloped in its sheath, Sir Charles Bell says: "If we take up a nerve to examine it, we find that it consists of distinct filaments; but there is nothing in these filaments to distinguish them from each other, or to declare their offices. One filament may be for the purpose of sensation; another for muscular motion; a third for combining the muscles in the act of respiration. But the subserviency of any one of these filaments to its proper office must be discovered by following it out, and observing its relations, and especially its origin in the brain and spinal marrow. In their substance there is nothing particular. They all seem equally to contain a soft pulpy matter enveloped in cellular membrane or pia mater, and so surrounded with a tube of this membrane as to present a continuous track of pulpy nervous matter, from the nearest extremity in the brain to the extremity which ends in a muscle or in the skin.

"Previous to the observations which I have made, such a nerve as I have described was supposed to have all its threads alike; they were supposed to be branches from the same root, and all capable of exciting a muscle or conveying a sensation.

"The key to the system will be found in the simple proposition, that each filament or trunk of nervous matter has its peculiar endowment independently of the others which are bound up along with it; and that it continues to have the same endowment throughout its whole length. If we select a filament of a nerve, and if its office be to convey sensation, that power shall belong to it in all its course wherever it can be traced; and wherever in the whole course of that filament, whether it be in the foot, leg, thigh, spine, or brain, it may be bruised or pricked, or injured in any way, sensation and not motion will result; and the perception arising from the impression will be referred to that part of the skin where the remote extremity of the filament is distributed."

The two conditions of nervous conduction so clearly indicated in this passage, namely, that each primitive fibre presents " a continuous track from one extremity to the other," and that it performs one single office only, which it cannot transfer, and which cannot be substituted for another, constitute the two fundamental conditions of nervous conduction, which, in honour of the illustrious man who discovered and established them, it has been agreed by common consent to call the Lex Bellena.

What Bell thus by the penetration of his genius and without ocular demonstration discovered, subsequent microscopic observation has confirmed; and there is not in the whole range of human knowledge a more exquisite instance of what has been well termed " anticipations of science."

It is like the mental view obtained by Copernicus of the phases of the planet Venus, and which he declared would be manifest to every eye if ever the telescope should become sufficiently powerful to display them.

" It had been objected to the doctrine of Copernicus," says Sir John Herschel, " that were it true, Venus should appear sometimes horned like the moon. To this he answered by admitting the conclusion, and averring that, should he ever be able to see its actual shape, it would appear so. It is easy to imagine with what force the application would strike every mind when the telescope confirmed this prediction, and showed the planet just as both the philosopher and his objectors had agreed it ought to appear. The history of science affords perhaps only one instance analogous to this. When Dr. Hutton expounded his theory of the consolidation of rocks by the application of heat at a great depth below the bed of the ocean, and especially of that of marble by actual fusion, it was objected that, whatever might be the case with others, with calcareous or marble rocks, at least, it was impossible to grant such a cause of consolidation, since heat decomposes their substance, and converts it into quicklime, by driving off the carbonic acid, and leaving a substance perfectly infusible, and incapable even of agglutination by heat. To this he replied, that the pressure under which the heat was applied would prevent the escape of the carbonic acid; and that being retained it might be expected to give that fusibility to the compound which the simple quicklime wanted. The next generation saw this anticipation converted into an observed fact, and verified by the direct experiments of Sir James Hall, who actually succeeded in melting marble by retaining its carbonic acid under violent pressure."

There are in the history of physiology at least two instances of these triumphs, as brilliant as the preceding: the affirmation of the existence of a capillary system of vessels between the arteries and veins by the discoverer of the circulation of the blood, and the like positive affirmation of the continuity and insulation of the primitive nerve-fibres by the true interpreter of nervous structure. "Neither Harvey nor Bell," says Mr. Grainger, "saw with the bodily organ the great cardinal facts they so confidently proclaimed—the junction, that is to say, in the one case, of the arteries and veins by means of the capillary vessels, that subtle link in the circle of the blood; and in the other, the individuality of the primary nerve-tubules;"* but, nevertheless, they saw them by the force of their intellect with the distinctness of actual vision. And subsequently came the microscope, which rendered them visible to other and to all eyes, displaying in the one case the intervening capillary apparatus, and in the other the whole apparatus of nervous conduction; namely, the nerve-fibres intimately intermingling, never uniting, but each holding on its separate course; the thread of nervous substance in the centre of the tubule, the axis cylinder, the true conducting part, completely surrounded by its insulating envelope, the white matter of Schwann, and perhaps also the neurilemma, which is to the nerve-fibre precisely what silk or any other non-conductor of electricity is to the electric wire, preventing the electric fluid from passing into the surrounding medium.

The difference in the relation of blood-vessels to each other, and of nerves to each other, places in a striking point of view the essential characters in the structure and function of a nerve here insisted on.

In blood-vessels there is a true anastomosis; a direct opening from the cavity of one vessel into that of another; so termed from *ανα*, through, and *στομα*, a mouth; a mode of communication which secures an uninterrupted circulation; while it matters not to an organ, provided it receive a due supply of blood, by what particular channel it is conveyed: but were the nerve-tubules thus to anastomose, the transmission of nervous force to a single point, the conveyance of a distinct impression, would be impossible. If the cerebral extremity of a tubule be connected by a single point with the nervous centre, and its cutaneous extremity by a single point with the skin, it is easy to conceive how a definite impression made upon the point of the skin may be communicated to the point of the brain. If, corresponding to the many thousand tubules which are given off to the peripheral parts of the body, there are precisely the same number of points represented in the brain, there is no difficulty in understanding how any number of definite impressions may be conveyed to the brain. But if the nerve-tubules were to anastomose like the blood-vessels, the irritation of a single point at the skin must necessarily be propagated through all the anastomoses, and consequently no definite impression could be communicated or received.

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* Grainger's Hunterian Oration on the Cultivation of Organic Science.

After what has been stated, little need be added to prove that nerves are really the carriers of a force generated in the centres. As long as a nerve remains in connection with its dynamic centre, it is capable of performing its office: when that connection is severed its power ceases. If the connection of a spinal nerve with the spinal cord, for example, is cut off, irritation of the peripheral extremities of the nerve no longer produces spinal action: if the connection of a sensory nerve of the skin with the brain be interrupted, no amount of irritation of the skin will produce sensation: restore the connection of the nerves with their respective centres, and the phenomena proper to the action of each are reproduced.

Separation of a nerve from its centre, not only deprives it of its functions, but destroys its life, and causes its disorganisation. If the sciatic nerve, for example, the great nerve which supplies motor and sentient power to the lower limb, is divided, paralysis of the limb and loss of sensation, which immediately follow, are succeeded in a few days by an organic change in the structure of the nerve: the contents of the tubules curdle and recede from the edges of the sheath; in a few days more the white matter of Schwann and the axis cylinder are mixed and blended together, and ultimately the tubules shrivel up and become completely granular.

Sometimes, however, a divided nerve is reunited. Even the spinal cord itself, after a complete section of it, may repair the injury by a perfect reunion, so that motion and sensation, which had been lost, are restored.

On examining the part at which the process of reparation has taken place, it is found that great numbers of nerve-tubules traverse the cicatrix and run uninterruptedly through it. These are regarded as new productions.

Nervous conduction includes—

1. Conduction of sensation, by a distinct set of nerve-fibres, the sensory, in uninterrupted communication at one extremity with a sentient organ, and at the other with the cerebral centre.

2. Conduction of voluntary motion, by another set of nerve-fibres, the motor, in like uninterrupted communication by one extremity with the cerebral centre, and by the other with the voluntary muscles.

3. Conduction of reflex motion, by a third set of nerve-fibres, in uninterrupted communication by one extremity with the spinal cord, and by the other with the involuntary muscles.

Conduction is called into action only on the application of a stimulus. Nerves are charged with nervous force just as a Leyden jar is charged with electricity; but they do not give it off until their passive state is changed, by the application of some physical or mental stimulus which disturbs the equilibrium of the force, thereby affecting every ultimate atom making up the nerve-fibre in the manner, it may be inferred, which is called induction in electricity.

That property of a nerve by which it manifests its endowments under the influence of a stimulus is termed its excitability. By virtue of this property, a stimulus applied to the nerve-fibres for sensation excites sensation, and to those for motion, motion. Since stimuli excite in succession the ultimate component atoms of the nerve-fibres, it follows that every action of a stimulus is at the expense of this matter. A portion of it is used up in and by every excitation. The more violent and the longer continued the action, the greater is the expenditure of the nervous matter. Hence the exhaustion and waste caused by the daily actions of life. When these actions are normal, the daily waste is never greater than is compensated by the daily deposit of new matter by the process of nutrition; but when the action is greater than natural, or more uninterruptedly continued, a longer time is required for repose, during which new matter may be supplied and appropriated.

We are made conscious of these laws of excitability by the daily exercise of our senses and muscles. The longer the eye is fixed upon a coloured object, the less distinct becomes the colour, until at length it is lost, and the object becomes grey. The retina acted on by the stimulus of light becomes very rapidly exhausted, and at last insensible; the exhaustion being proportionate to the degree and persistence of the previous excitement. So with muscles. The longer and more forcible the contractions of the muscles of the arm, the greater their exhaustion and the longer the time required for the renewal of their excitability by their reception and appropriation of new supplies of blood.

But a stimulus may be so violent as instantaneously to annihilate the excitability by the destruction of the nerve itself, like mechanical pressure by which the primitive fibres are crushed; the application of a chemical agent by which they are decomposed, or a stroke of lightning by which they are disorganised.

On the excitability of the nerves which supply them depends the action of all the organs of the body. In its normal state every organ is always in contact with its appropriate stimulus. By the influence of that stimulus on its nerves, its action is excited and maintained.

All the actions of life therefore are the result of stimuli. Life is a forced state, and is maintained only by an unceasing supply of stimulants. Lessen the stimulants, the actions are enfeebled; increase them beyond a certain point, the actions are excessive, at the expense of the integrity of the nervous substance: take them away altogether, the actions stop; supply them with constancy and in due moderation, then and then alone are the actions carried on with their full and proper vigour, and capable of continuing during the whole term naturally assigned to them. The practical importance of a knowledge of these laws, in the regulation of the conditions on which physical and mental health and strength depend, in the conduct of physical and mental education, and in the modifications required at the different epochs of life, in infancy, in childhood, in manhood, and in old age, will be shown in detail hereafter.

CHAPTER XXII.

STRUCTURE OF THE SYMPATHETIC OR GANGLIONIC CENTRE.

The greater part of this system is termed the sympathetic, from an ancient notion that the so-called sympathetic nerve, from its peculiar relation to other nerves, is the cause of that wonderful consent and sympathy which exists between all parts of the animal body. But this nerve does not appear to possess anything really distinctive in this respect, beyond the comparative number of its branches, and its consequent more extensive connections.

This division of the nervous system is also called the ganglionic, from its being composed chiefly of the bodies called ganglia; and the organic, from its being supposed to preside over the functions of the organic or vegetative life.

The ganglionic system, in its whole extent, includes the ganglia of the great sympathetic (Fig. 102); the ganglia of the posterior roots of the spinal nerves; those of several cerebral nerves; and those in the substance of organs, together with their respective communicating branches. Anatomically all these organs are essentially the same, and therefore form one system.

The sympathetic part of the ganglionic system, however, to which the term sympathetic is restricted, consists of a series of ganglia united by connecting cords, forming what is called the trunk of the great

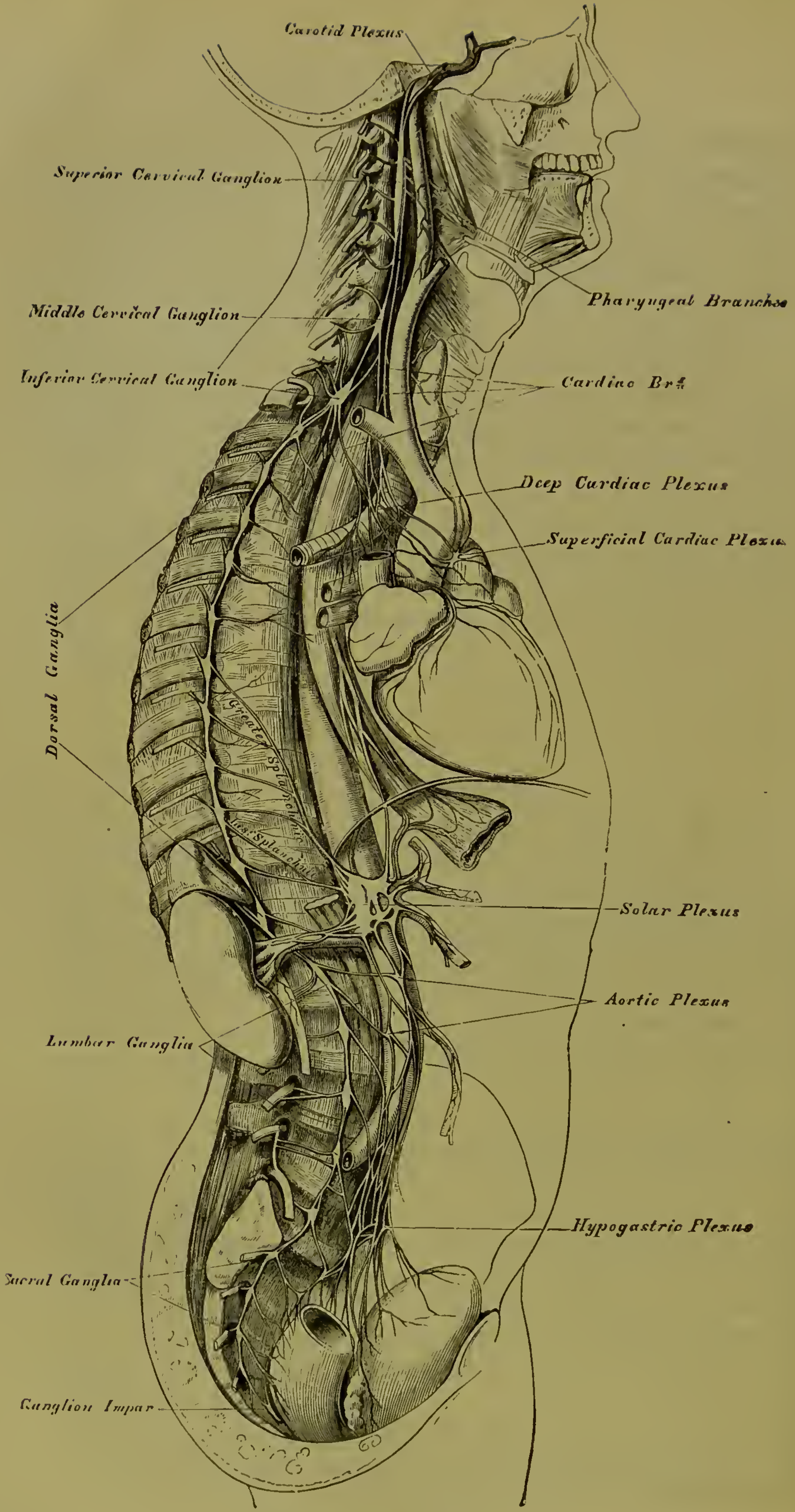

Fig. 102.—The sympathetic nerve.

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sympathetic nerve (Fig. 102), which, from the fact of its having these ganglionic active masses, must of course be distinguished from the trunk of a common nerve.

On this so-called trunk there is a pair of ganglia corresponding with each pair of cerebro-spinal nerves (Fig. 102). These taken together form a series of ganglia extending from the head to the pelvis (Fig. 102). From this account it would follow that there should be a pair of ganglia to each vertebra; but owing to the fact that in certain regions several of the ganglia coalesce, this total number is proportionally reduced, so that it is usual to enumerate on each side of the body three cervical (Fig. 102); eleven thoracic; four lumbar; and five sacral. In addition to the preceding are the ganglia connected with the nerves of the head and also several large ganglionic masses, centres of nervous force, as the cardiac ganglion, connected with the heart (Fig. 102); the semilunar ganglion, composed of numerous ganglia, and these again of still smaller ones, placed in the abdomen (Fig. 102), and supplying its viscera.

One of the main points in the anatomy of the sympathetic system relates to the mode of connection between the ganglia placed on the so-called trunk of the nerve and the cerebro-spinal nerves. This connection, which is complex, consists of four small fibres (Fig. 102), extending from each ganglion, a thoracic ganglion, for example, and the neighbouring spinal nerves. Of these, two are grey, consisting of the grey fibres immediately to be described, which pass between the ganglion and the anterior and posterior root respectively of the spinal nerve (Fig. 102): the other two are ordinary white nerve fibres, passing between the anterior and posterior root of the spinal nerve respectively, and the adjoining ganglion. Each of these communicating branches has its special office, as will appear when the physiology is considered.

The structure of all the ganglia, as just stated, is essentially the same. They are all composed of an intimate union of vesicular and tubular neurine, and in this respect their organisation is strictly analogous to that of the other nervous centres. The vesicles of the grey matter of the ganglia, however, are smaller than those in the corresponding part of the cerebro-spinal system, varying in size from the $\frac{1}{1800}$th to the $\frac{1}{2800}$th of an inch. Great numbers of them, like those in the latter system, send off delicate prolongations, commonly one at each end, precisely similar to those described as caudate processes. These vesicles here take the name of ganglionic caudate vesicles.

The fibrous portion of the ganglia is more peculiar than the vesicular. On examining under the microscope the fibres that enter into the composition, either of the communicating or main branches of the sympathetic, it is found that they consist of two distinct orders of fibres, which differ from each other by broadly-marked characters, by colour, consistency, and distribution.

The fibres of one set are smaller than those of the other, being scarcely more than half their size; they are softer, almost transparent, their contents being apparently nearly uniform, and they are of a dark-brown, or, when collected in bundles, of a yellowish-grey colour. The other set besides being, as just stated, one half larger than the other, are much firmer, and of an opaque pearly white colour.

The first are termed "fine fibres," or more commonly "grey fibres." They are the proper fibres of the ganglionic system. They are new fibres apparently generated in the ganglia. They are seen to arise from the caudate vesicles, and are, in fact, a prolongation of them.

This is proved by tracing a caudate vesicle onwards (Fig. 98), when it is seen to be directly continuous with the tubule, the contents of the former flowing into the latter. But the nerve fibres thus formed are destitute of the solid medullary substance of the cerebro-spinal nerves, the white matter of Schwann. Hence their distinctive characters, their comparative softness, their transparency, their fineness, and their grey colour, probably derived from the grey colour of the vesicular neurine itself.

The grey efferent ganglionic fibres go out from the ganglia, and are distributed—

1st. To the viscera, as the heart, the stomach, the liver, the intestines, the kidneys, and so on. The nerve fibres are placed on the great arterial trunks that carry arterial blood to their organs, and nerves accompany the blood-vessels to their minutest ramifications.

2nd. In the manner already described, to the spinal and cerebral nerves, with which they intermingle, and which they accompany in their course to all the tissues and organs of the body..

Thus the ganglia form a system of gelatinous nerve fibres, which partly in company with blood-vessels, and partly with cerebro-spinal nerves, are distributed everywhere over the body.

On the other hand, the large, firm, white fibres, which are found interspersed with the grey, are derived from the cerebro-spinal centre, from which latter they can be traced into the ganglia. On reaching the ganglia they undergo no increase, and they do not appear to have any intimate connection with the caudate vesicles, but merely pass between them.

From the preceding account it is clear that the cerebro-spinal nerves which communicate with the ganglia are derived from both their posterior and anterior roots; so that the ganglia unquestionably receive both sentient and motor fibres The number of cerebro-spinal nerves which unite with the ganglionic is, however, so small that their natural silvery colour is obscured by the abundance of the grey; while in their turn, the grey fibres which mingle with the cerebro-spinal, are comparatively so few that they are seen merely as grey fibres in a large mass of white.

It thus appears that by the communicating branches which have been described, an intimate connection is established between the cerebro-spinal nerves and the sympathetic trunks in their entire course: so that in every part of the body all sympathetic nerves contain some intermingled spinal and cerebral nerves, and all cerebral and spinal some sympathetic.

CHAPTER XXIII.

FUNCTIONS OF THE SYMPATHETIC OR GANGLIONIC CENTRE.

The ganglia constitute distinct nervous centres, connected with, but independent of, the cerebro-spinal system.

That they are distinct nervous centres is evinced by the preceding account of their structure and relations. They are all composed of vesicular and tubular neurine; they receive nerve fibres from the other centres; they generate new and peculiar fibres of their own, and they send out these fibres to all the organs and tissues of the body. Each ganglion with its central grey matter, and its afferent and efferent nerve fibres, may indeed be regarded as an example, or type, of a simple nervous system, communicating its peculiar influence to the organs with which it is placed in relation. In the multiplication and separation of its individual parts, the ganglionic centre differs widely from the spinal and cerebral centres, which are characterised by their consolidation and concentration; a difference of arrangement connected, without doubt, with the different modes in which they perform their respective functions.

That the ganglionic centres are independent of the cerebro-spinal system is proved by the fact, that when their connection with the brain and spinal cord is entirely removed, the parts supplied by them continue their natural action for some time; but their close connection with the other centres will appear immediately.

Ganglionic nerves are conductors of nervous force from their own centres, just as the cerebro-spinal nerves are from the spinal cord and brain; but their mode of conduction is modified in several respects, presenting very important and interesting differences.

1. Ganglionic conduction is slower than cerebro-spinal, or, at any rate, than cerebral conduction. I will to move my arm. There is no

appreciable distance of time between the act of volition and the action of the voluntary muscles; but if a stimulus be applied to the stomach, or the intestines, the result is not immediate; there is no action for some seconds; and when it does take place it is slowly progressive, attaining its highest degree of force a considerable time after the exciting cause has been removed. If the influences of volition on muscular action were not instantaneous, the object of volition would be lost; if the gastric and intestinal movements were thus sudden and rapid, the object of their motions would be defeated.

2. It is more diffusive than cerebro-spinal conduction. A stimulus applied to a ganglionic fibre going to a particular part of the intestines, for example, produces its characteristic movement over a considerable extent of the alimentary canal: applied to a cerebro-spinal fibre, it excites the action of that particular muscular fasciculus only to which such fibre is distributed.

3. It is more regular and measured. The movements of respiration, which is a mixed function, are regular indeed, but the motions principally under the government of the ganglionic centres are so orderly and successive, that they are justly termed rhythmical. The action of the heart is strictly rhythmical. Its auricles and ventricles alternately contract and dilate at measured intervals of time. A nervous current is periodically transmitted to it from its centre, and the periodic action that results is continued uninterruptedly from the first to the last moment of life.

The motion of the intestines is equally periodic and rhythmical. This singular movement, sometimes termed vermicular, or worm-like, and at others peristaltic, from περιστελλω, to contract, consists of contractions which succeed each other, like waves, from above downwards; a second wave commencing before the first has traversed the whole intestine. There is no apparent motion directly downwards, yet on the whole the motion is downwards; the object being not only to carry downwards the alimentary mass, but while thus transmitting it ultimately in that direction, so to move it as fully to expose it, in its progress, to the mouths of the absorbents.

4. Ganglionic, like spinal conduction, is incapable of exciting any movements without the presence of a chemical or physical agent. In this respect, both these centres differ widely from the cerebral centre. A thought, a volition, can excite a voluntary muscle, but unless some foreign body, some physical or chemical stimulus be in contact with a ganglionic organ, that is, with the nerve fibres spread out upon its surface, there can be no action. Naturally every such organ is provided with its own appropriate stimulus, by which it is ordinarily influenced; the heart and blood-vessels by the blood; the stomach by the food; the intestinal canal by the food; the secreting ducts by their

own contents, as is seen in the flow of the bile along the biliary ducts to fill the gall-bladder, when there is no food in the duodenum; and when food is there, and the contents of the reservoir are needed, it is excited to yield them up by a stimulus propagated from the intestine along the ducts of the gall-bladder. In the case of the stomach, the stimulus of the food excites the secretion of the gastric juice, which flows as long as the stimulus is present, but no longer. In this instance, the pouring forth of a solvent fluid is caused by the irritation of the identical substance to be acted upon—the food, which thus becomes the producer of its own solvent.

In some instances the surface destined to be in contact with the stimulus is endowed with a peculiar irritability. This seems to be especially the case with the heart, for if opium or strychnine be applied to the external surface of the heart, little or no effect is produced; but if a small quantity be brought into contact with the inner surface of the auricle or ventricle, the movements of the organ are permanently arrested in a few seconds; hence the rapidity of narcotic poisoning when once the poison has entered the blood and reached the heart.

5. Lastly, in this respect also, like the movements under the influence of the spinal centre, those dependent on the ganglionic centre are involuntary. The purposes they answer in the economy could not be fulfilled unless they were constant, unless they were unfailing; but the will is inconstant, unstable. They are, therefore, withdrawn from its influence. They are made independent of it. On the contrary, the muscles excited by the cerebral centre are the servants of the will, whose commands they receive and execute with the rapidity of the electric current. How is this difference of action produced? Why does the deltoid contract on a thought of the mind? Why can no voluntary effort of the mind produce the slightest change in the orderly contraction of the intestines? We see, first, that there are manifest differences of structure between the nerves and muscles of the two respective systems, indicative of a difference of function; and we know, further, that the two classes of muscles are placed under different centres. The deltoid contracts at the command of the will because it is under the control of the brain; the intestines do not contract at the command of the will because *their* muscular fibres are under the control of the sympathetic, not the cerebral system. The reason, or final cause, of this fundamental difference in their modes of action will be seen immediately.

The special function of that portion of the ganglionic centre which comprises the proper sympathetic appears to be to excite and regulate the movements which convey the material of nutrition—arterial blood—to the nutritive organs. The mass of its fibres, those assemblages which we have seen connected with the great ganglia in the abdomen, and which may be regarded as the centre of the system, are placed on the trunks of the arteries which supply the pelvic, abdominal, and thoracic viscera, all organs which minister directly or indirectly to the processes of nutrition. The nerve fibres are distributed to the muscular or contractile coat of the arteries, and accompany them in all their ramifications as far as their muscular coat extends, that is, to their capillary divisions, where both the nerve and the muscular fibres definitely cease together. Everywhere the ganglionic nerve accompanies its nutrient artery inseparably, and everywhere their action is mutual and synchronous: the nerve, the governing power, exciting and controlling the action of the artery, regulating the number and force of its contractions, determining the quantity of blood delivered to each organ in a given time, and the mode of its delivery, and thus exerting an all-powerful influence over the essential conditions of vital chemical action and reaction—that is, nutrition.

The controlling power of the ganglionic nerve over the supply of arterial blood, is strikingly shown on separating such a nerve from its corresponding artery. If the nerve be divided, the arterial branches supplied by it are instantly paralyzed. They can no longer perform their office. On the other hand, the entire destruction of the spinal cord and brain does not arrest the circulation; for in the web of the frog's foot the blood is seen to flow long after the spinal cord and brain have been removed from the body, in which case the circulation must be maintained by ganglionic nerves, for there are no others left.

The nerves give to the arteries their carrying power, but probably they do nothing more. On delivering the blood to the apparatus in which it is to be used, the office of the nerve appears to be fulfilled; on the use of it, on the process it has probably no influence. That process in the animal, as well as in the plant, is a purely physico-chemical action. Nerves and muscles are superadded to the animal body, engrafted on the structural basis of the plant; but the vegetative processes in the animal obey the same physical laws as in the plant. The new organs are additions, not substitutions; and evidence will be adduced hereafter to show that they directly act and react on each other *only*, however they may indirectly modify the organic processes.

The ganglionic centre, then, is so far the governing power of nutrition that it is the source of the vital actions by which the physical elements of nutrition are brought into actual contact, or into sufficient proximity to enable them to act and react on each other; a function which is indeed essential to nutrition in the animal body, but which is still only the minister to the function, not the function itself.

With respect to the functions of the other portion of the ganglionic centre, namely, of the ganglia which are placed on the posterior roots of the spinal nerves, it is generally supposed that these ganglia also are, in some way or other, like those of the proper sympathetic, connected with nutrition. But this is not proved; and the fact that these ganglia are invariably placed on the sentient roots of nerves, and that on one at least of the nerves of special sense—the olfactory, the nerve of smell—there is a distinct ganglion, well seen in fishes, would rather indicate that the ganglia on the posterior roots of the spinal nerves constitute a necessary part of the nervous apparatus of sensation than of nutrition.

The preceding account of the anatomy of the ganglionic system demonstrates that all ganglia are supplied with sentient nerves, derived from the cerebro-spinal system, which ramify through their substance, intermingle with their own fibres, and go out with them to the organs. Parts chiefly supplied by ganglia are, therefore, not altogether destitute of sensibility, but it is very obscure, exciting no distinct sensation. Their sentient nerves would appear to be too few in number to communicate distinct feeling under the ordinary impressions they receive. In a state of health they carry on their processes without consciousness. Violent, long-continued irritation, indeed, rouses their latent sensibility, and then they produce intense pain, as is too fully proved by the suffering caused by diseases of the abdominal and other viscera. But even under these circumstances they give rise to no sensation excepting that of pain.

Anatomy further shows that the ganglia are supplied with motor fibres from the anterior roots of the spinal nerves: hence, organs chiefly supplied by ganglia are capable of movements which can be excited only by the cerebro-spinal centre. Passion instantaneously affects the action of the heart by an influence transmitted directly from the brain through the cerebral fibres that join the ganglionic. Irritation of the spinal cord disturbs the action of the heart sometimes to such a degree as to simulate organic disease of the heart, as in spinal neuralgia, in which there is violent disturbance of the heart, though the seat of the disease is in the spine. So in children, irritation of the intestinal canal by the presence of worms often produces violent convulsions. The irritation is transmitted by the nerves of the intestines to the spinal cord, and is thence reflected by the spinal nerves to the muscles, which are thereby excited to violent contractions. All spasmodic affections arising from local irritation of the abdominal and other viscera are produced in the same manner.

The peculiar relation thus established between the ganglionic and the cerebro-spinal system presents an adjustment which cannot be contemplated without admiration. The intermixture of the two systems which has been described, and the exact balance established between them, are essential to the well-being of moving and sentient creatures, and their welfare is secured as much by what is excluded as by what is included, by the precise limit set to sensation and volition, as by the introduction of these faculties at all. Had the action of the heart, for example, been voluntary and sensible, life must have been spent in attending to it; the occupation must have been exclusive, and without intermission. Every step in every movement of the body from place to place must have required a distinct effort of the mind; the approach of almost every foreign body would have excited terror; there could have been no sleep and no rest. The convenience and pleasure of existence, nay, even existence itself, depend on the uninterrupted action of the heart: it is, therefore, made to work without consciousness, without fatigue, and without the necessity of continuous rest.

And yet had the heart been rendered wholly insensible: had the stomach, the liver, the intestines, and all the other vegetative organs, been so constructed as to carry on their processes without any kind or degree of sensibility, one main source of the pleasure and the safety of life must have been lost. But by joining in inseparable unions sentient with insentient nerve fibres, and by making the insentient greatly predominate in the vegetative organs, a certain amount of sensibility is communicated as these processes go on, not amounting to distinct, discriminative sensation, but yet producing that indistinct, that pleasurable consciousness which is felt in every fibre of the frame in sound and vigorous health; while by the same admirable arrangement, when any considerable deviation from the state of health occurs, warning is given of the danger, and pain is made the minister of safety. Thus are the two lives blended together that they may work in harmony, and thus the foundation of pleasurable existence is laid in the action of the primary and fundamental processes of life.

CHAPTER XXIV.

STRUCTURE OF SPINAL CORD.

Provisions for the protection of the cord—Ligaments by which it is slung and fixed—Suspended in fluid—Arachnoid pouches—Form and extent of the cord—Composed of white and grey neurine—Connection of spinal nerves with cord—Course of the fibres of the nerve-roots—Incident and reflex fibres—Sensitive and volitional fibres.

The spinal cord is an extended mass of neurine, consisting of fibrous and vesicular matter intimately united. It is lodged in a bony cavity formed by a series of bones termed vertebræ, from *verto*, to turn, because the bones that compose the column move or turn upon each other.

The cord extends from the border of the foramen magnum, where it enters the cranium, to the lower part of the vertebral canal, where it terminates at the second lumbar vertebra (Fig. 32).

The integrity of the spinal cord being essential to actions indispensable to life, extraordinary provisions are made for its protection and nourishment.

1. The first and main protection of the cord is afforded by the bony case in which it is enclosed, the construction of which presents one of the most admirable pieces of mechanism in the animal body, combining apparently incompatible conditions, and accomplishing in the most perfect manner purposes directly opposed to each other.

Between the bodies of the firm and solid bones which compose the spinal column, there are placed large masses of elastic matter, called the Intervertebral substance. This substance consists partly of cartilage and partly of fibrous matter, disposed in concentric plates, and forming large discs, one of which is placed between each pair of vertebra, excepting the two first, so that they amount in number altogether to twenty-three (Fig. 42). They constitute so many elastic springs, which form a much larger part of the entire column than is commonly conceived. According to the accurate measurements of Weber, they make up rather more than one-sixth part of the whole * length of the column. They perform the double office of uniting the vertebræ to each other as ligaments, by firmly tying the bones together, and yet so as to give to the entire column a considerable degree of mobility.

2. The curvatures of the column, in conjunction with the elastic discs just described, afford a second protection to the cord. The natural curvatures of the column are considerably greater than are

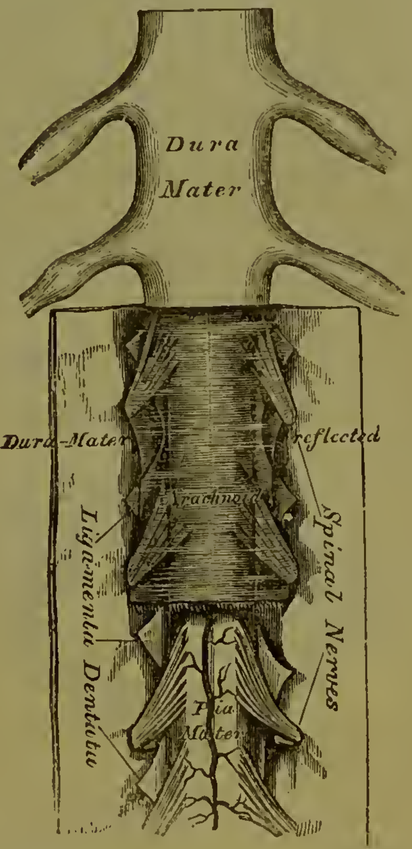
commonly represented, as is shown by Fig. 42. These, together with the elastic matter, allow the column to yield when violent force is applied to it, and thus prevent the concussion which would have arisen, not only to the cord, but also to the brain, if that organ had been placed on the top of a rigid and straight column, instead of a curved and elastic one.

The principal point at which all the concussions are received, and which are transmitted to the column from the lower extremities, in running, leaping, and so on, is where the great bones of the pelvis are united to the sacrum, termed the Sacro-iliac Junction, or Symphisis. From this point the force is propagated to the lowest lumbar vertebra, and thence upwards along the column. As the elastic matters increase successively in the same direction, it follows that the successive segments of the cord are brought proportionately within this protective agency—a mechanism which explains, first, why the cord, instead of descending to the lowest point of the vertebral canal in the sacrum, ends, as has been stated, at the second lumbar vertebra, that is, several inches above the place where the great concussions happen in all the above-named movements; and, secondly, assigns the reason of a still more interesting adjustment in relation to two great vital nerves—the pneumo-gastric, which go to the lungs, and are the exciters of respiration, and the phrenic, which supplies the diaphragm, the great motor agent in that process. These nerves, instead of coming off from the spinal cord nearest the organs they supply—the lungs and diaphragm—according to the ordinary rule, arise, the first actually within the skull, and the second opposite the third vertebra of the neck. Why do they take this unusual course? Suppose, in consequence of a violent concussion, injury is done to the cord, say in its dorsal portion, a result which is often seen in the practice of surgery. By such a lesion, the powers of this portion of the cord are suspended; paralysis takes place below the part injured, but life is not destroyed. After a time the injured part recovers from the shock: its functions are restored, and the temporary paralysis passes away. Had these two vital nerves taken their origin in the dorsal region in the ordinary manner, such an injury would have destroyed life instantaneously, by arresting respiration.

3. The third provision for the security of the cord is derived from the membranous envelopes in which it is enclosed. These are three in number. The inner one, which immediately surrounds it, is termed the Pia Mater (Fig. 103). It affords the cord a protective covering; but it is also the principal medium through which it receives its supply of blood, and, therefore, its nourishment.

There is something very remarkable not only in the vast amount of blood which is sent to the cord, but also in the distribution of the blood-vessels by which it is supplied. The arteries, four in number, do not, like the common arteries of the body—as they give off branches in their course—become progressively smaller and smaller, but they continue of the same size throughout, because they receive reinforcements from the neighbouring arteries as they proceed all the way down the cord.

Fig. 103.



The spinal cord and its membranes.

At the base of the skull a large and free communication is established between the veins of the cord and those of the brain, the latter called, from their winding course, sinuses. Besides these, there are three special systems of veins proper to the cord, one placed external to the vertebral column, another within the vertebral cavity, but external to the Dura Mater, and a third within that membrane, and lodged in the Pia Mater. The freest communication is established between all these systems of vessels, that no stoppage in the circulation may take place at any point, and that danger to the cord from their undue turgescence may be obviated.

Lying loosely upon the Pia Mater there is a second membrane, likened, for its extreme tenuity, to the spider's web, and so called the arachnoid membrane (Fig. 103), from *αραχνη*, a spider. It is a serous membrane, and, like all membranes of its class, is reflected upon itself, and forms a closed sac, in the interior of which a minute quantity of fluid is secreted, merely sufficient to prevent the agglutination of its two surfaces.

The third and external covering of the cord is derived from the Dura Mater (Fig. 103), which, after having given an internal lining to the bones of the skull, and an outer envelope to the brain, passes down into the vertebral canal, completely envelops the cord, and here takes the name of Theca Vertebralis, from the Latin, *Theca*, a sheath, because it envelopes the cord as in a sheath.

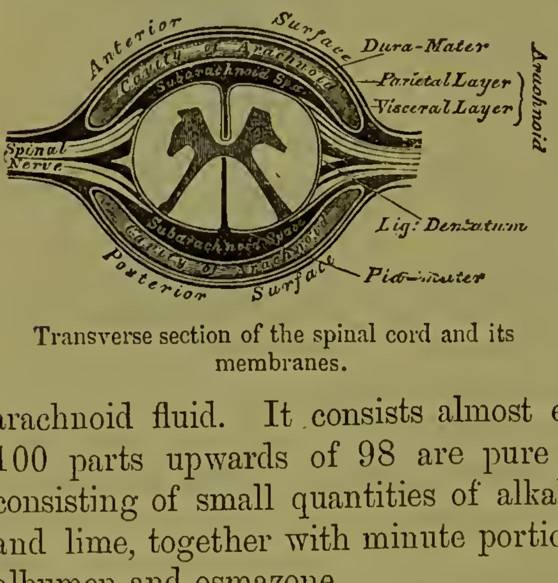
The Theca Vertebralis differs from the Dura Mater in being more elastic, and, therefore, better fitted for its special office in relation to the cord, and in not giving an internal lining to the vertebræ, as the Dura Mater does to the bones of the skull. The vertebræ are covered by a periosteum of their own, like the bones of the body in general; and hence the Theca Vertebralis is devoted entirely to the cord. So far, indeed, from adhering to the vertebræ, the periosteum is separated from them by a layer of fat and areolar tissue, which surrounds it in its whole course, thus acting as an elastic cushion.

The cord is suspended and maintained in its position in a remarkable manner. Proceeding from each side of the cord to the Theca Vertebralis, to which it is attached by a number of pointed processes (Fig. 103) like the teeth of a comb, there is a delicate but firm membrane, which derives its name from these tooth-like processes, and is hence called the denticulated ligament (ligamentum denticulatum). This membrane suspends and steadies the cord in the centre of its bony canal, just as if it were sustained in a sling.

At the lower part of the vertebral canal the Theca ends in a number of strong elastic cords, which are attached to the last bone of the column, the os coccygis, and these, like the stay ropes of the mast of a vessel, fix and firmly hold the cord vertically, as the denticulated ligaments do laterally.

4. A fourth contrivance for the protection of the cord is a very subtle and unexpected one. It has just been stated that the arachnoid membrane lies loosely upon the Pia Mater. Between the two membranes there is a considerable space (Fig. 104), which is occupied by a very remarkable fluid of signal importance. It is termed, from its position beneath the arachnoid, the subarachnoid fluid. It consists almost entirely of water; that is, out of 100 parts upwards of 98 are pure water, the remaining two parts consisting of small quantities of alkaline substances, as soda, potass, and lime, together with minute portions of animal matter, principally albumen and osmazone.

Fig. 104.



Transverse section of the spinal cord and its membranes.

This fluid, which is very considerable in quantity, extends the whole length of the vertebral canal, and, as there is no division between the vertebral and cranial cavities, the fluid passes freely from the former into the latter, where it occupies precisely the same relative situation; and hence, being common to both cavities, it is further called the cerebro-spinal fluid. In the living body it is not stagnant. It is in a state of constant, gentle oscillation, so that in a living animal it may be seen to rise and fall with the movements of the chest in respiration. That it may be defended from all injurious contact with the bony walls of the canal in which it is encased, and that it may be farther protected from concussions propagated through these walls, the cord is slung by the mechanism just described in the centre of this fluid, which exerts upon it an equal, uniform, yet very considerable pressure.

5. The last provision for the protection of the cord which remains to be described is no less admirable than the preceding. All violent muscular exertion, such as straining, leaping, and so on, retards the return of the blood to the heart, and would, if not otherwise prevented, produce an accumulation of the fluid within the spinal and cranial cavities, already full, and thereby cause undue pressure upon the cord. To obviate this danger, an outlet, foreign to both cavities, is required, and is actually provided for the momentary retrocession, under these circumstances, of the cerebro-spinal fluid. Where each spinal nerve is about to escape from the vertebral canal, it receives a funnel-shaped pouch from the Dura Mater, which is lined by the arachnoid, and which is thereby brought within the sub-arachnoid space; that is, each pouch is thus placed in free communication with the sub-arachnoid fluid, These pouches are surrounded by soft and elastic tissue, and are consequently rendered yielding. The capacity of each little individual reservoir is indeed small; but as there are thirty-one pairs of them, or sixty-two in all, their aggregate capacity is very considerable. Suppose from some sudden and violent exertion the free return of the blood to the heart is prevented; immediately a tendency to accumulation of it takes place within the spinal and cranial cavities; but these cavities, as we have seen, are already full; their rigid walls will not yield: at that moment the cerebro-spinal fluid itself, in consequence of the unusual pressure exerted upon it, recedes into these arachnoid pouches, and thus instantaneously relieves the cord and brain from the remotest danger of compression.

Altogether, then, the position of the cord is this:—

1. It is lodged in a bony case, to which, while strong enough to bear heavy weights, and to resist great violence, a considerable degree of mobility is given by a series of elastic springs and joints.

2. It is protected from the concussions inevitably propagated through solid bones—first, by the curved form of the column, and, secondly, by the succession of elastic plates that tie the bones together.

3. It is guarded from friction by the elastic cushion which lines the whole interior of the canal in which it is enclosed.

4. It is enveloped in three membranous coverings.

5. It is slung by elastic cords in the centre of a fluid which is always maintained in sufficient abundance to exert upon it a moderate and uniform pressure.

6. It is secured from undue pressure either by this encompassing fluid, or from venous congestion, by numerous elastic outlets, which are always open to receive a portion of the fluid whenever, from temporary causes, a local or general over-fullness may occur.

When its envelopes are removed, and the cord is fully brought into view, it is seen to be nearly circular in form, though somewhat flattened. It is a compressed cylinder. It is not of the same size throughout its course. It increases in bulk at the parts where it is in connection with its principal nerves. Thus, an enlargement takes place at the lower part of the neck, where the nerves of the upper extremities are given off. In the dorsal region it diminishes in size, because there it gives off only the nerves of the trunk; while at the lower dorsal and upper lumbar regions it is larger than at any other part, because there it sends off the great nerves that supply the lower extremities.

It does not extend the whole length of the canal, but ends as a cord at the second lumbar vertebra. At this point it divides into a number of large and comparatively coarse bundles (Fig. 32) which, from their resemblance to a horse's tail, have received the name of Cauda Equina. The reason of its stopping and dividing at this point will be readily understood from what has been already stated. We have seen that at the lumbar vertebræ it is close to the region where all the great concussions take place. It does not actually descend into this region, but stops short several inches above it, where it divides into separate bundles, in order that the jars which do reach it may be received at many points instead of one, and that the several bundles formed by its division may each be individually surrounded by the protective fluid just described; the fluid itself being here also in greater abundance than in any other part of the canal.

The cord is composed of two symmetrical halves, placed with regard to the median plane laterally to each other (Fig. 104). It has thus two exactly corresponding portions. It is a double organ. Each half is a complete nervous centre, evidenced by the fact that if, in a living animal, the cord be divided longitudinally on the median line, each half carries on its respective functions.

The two halves are separated by two fissures, one on the anterior and the other on the posterior surface (Fig. 104), termed, therefore, the anterior and posterior median fissures. A commissure reunites the two halves, consisting of a band of white fibres that runs horizontally across the cord from one side to the other, thus connecting the corresponding halves together.

Each half of the cord, on both its aspects, is divided into four columns, the anterior lateral posterior and posterior median (Fig. 105).

On a mere external inspection, the cord appears to be composed entirely of white fibrous neurine; but on making a transverse section of it a large quantity of grey substance is found occupying its centre (Figs. 104, 105), and extending through its entire course, from the foramen magnum to the commencement of the cauda equina.

The arrangement of the grey matter throughout is definite and peculiar. It forms two semilunar masses, resembling two crescents placed back to back (Fig. 104), one horn being turned forwards and the other backwards, and hence they are called the anterior and posterior horns.

The two crescents are joined together by a band of grey matter, which stretches across the median plane thus)—(. This commissure unites the grey matter on each side of the median plane, and is of special physiological interest, since the grey neurine being the dynamic part, it establishes an active connection between the two sides of the cord, and, consequently, between the two sides of the body.

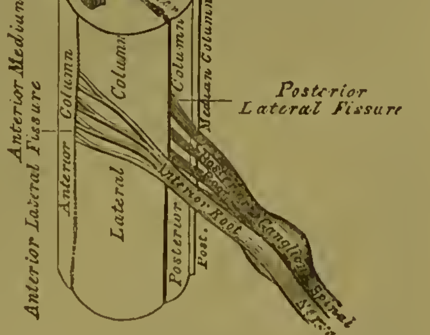
A narrow canal runs through the entire course of the cord, occupying its centre, and terminating superiorly in the fourth ventricle of the brain, into which it opens. It is lined throughout with epithelial cells, which proves that it is a definite structure, not an accidental product.

Briefly, then, the spinal cord may be described as consisting of a nervous mass, divided by an anterior and posterior fissure into two lateral portions, connected together by commissures, through which a very narrow canal runs, the two halves consisting internally of grey matter, expanded into two anterior and posterior horns, which are covered and enclosed by white substances, the latter being arranged into longitudinal columns.

The true origin of the spinal nerves is so intimately connected with the structure of the cord above described, that, although the details of these nerves will be given further on, it is desirable in this place to trace the complex communications of the nerve roots with the several component parts of the cord.

On approaching the cord, each spinal nerve divides into an anterior and posterior root (Fig. 105). On a superficial examination, these two roots appear to arise by delicate filaments from their respective lateral fissures on the surface of the cord. It is difficult to trace them beyond these points, into the interior of the cord, because the neurine so rapidly changes that in a few hours after death the soft and tender threads can no longer be distinguished. It is, therefore, extremely rare that an opportunity has been obtained of demonstrating their connection with the central grey matter in man. By repeated and skilful dissection, however, this has been effected. According to

Fig. 105.



Spinal cord—side view. Plan of the fissures and columns.

Mr. Grainger, who was the first to establish this anatomical fact, and whose dissections have removed the doubts which previously existed on the subject, the course of the nerve roots to their termination in the white and grey matter is this.

As soon as the two roots have perforated the Theca Vertebralis, and have thus reached the surface of the cord, the fibres of each root separate from each other; some of the diverging threads curve upwards, and proceed in a continuous course to the brain, along with the columns of the cord, while another set take an opposite course, and proceed transversely through the cord, until they reach the grey matter in which they are lost. It is only with extreme care that these most delicate filaments can be traced. As they proceed inwards they lose their rounded figure, become flattened, and before they are lost in the grey matter they appear merely as exceedingly delicate striæ, several of which may be counted from a single root. When the striæ meet the grey matter, they become encrusted by it, in accordance with a general rule. The dissections and figures given by Mr. Solly, from his own examinations, are in perfect accordance with the descriptions and drawings of Mr. Grainger.

What the scalpel and the naked eye were thus able to demonstrate, the microscope has fully confirmed. Dr. Julius Budge, of Bonn, aiding his researches by this light to science, states that the filaments of each root, immediately they penetrate the cord, divide into two fasciculi, one superficial and the other deep seated. The superficial become for some distance twisted or curved, and then directly ascend in the white substance towards the brain. The deeper-seated take a transverse course through the substance of the cord, until they reach the grey matter, into which they plunge, and where they are lost. Mr. Solly states that Mr. Grainger and himself have together repeatedly and carefully followed Dr. Budge's dissections, and that they can both speak decidedly as to their accuracy.

A further fact was noticed by Budge, and is confirmed by Grainger and Solly, to which an anatomist attaches much significance; that is, a particular disposition of the fibres of each nerve root, just as they are about to penetrate into the cord, consisting of an incurvation, or rather actual crossing, of the component fibres, preparatory to the division into the two bundles just described. This disposition is evidently of the same character, though not so marked, as that of the whole nerve itself when it divides into its anterior and posterior roots; and it may, therefore, be justly inferred that as the latter division indicates a distinction of function, the former has the same significance.

The great German microscopist Kölliker, in his very elaborate account of the disposition of the nerve roots, agrees, with some modifications, with these views. "The anterior roots," he says, "are continued in a transverse direction into the grey matter of the anterior horn by two fasciculi, one of which passes between the multipolar ganglionic cells, without uniting with their rays, extends to the anterior commissure, and finally passes into the anterior column of the opposite side of the cord, thus, according to him, producing a true decussation; while the filaments of the other fasciculi, taking no part in this decussation, enter the column of the cord, where they curve upwards, and appear as longitudinal fibres."

The course of the fibres of the posterior root, as described by this observer, is essentially the same.

Professor Vanderkolk, of Utrecht, who appears to have devised an improved method of preparing specimens for the microscopical examination of these delicate and complex structures, has given in great detail the results of his laborious investigations, which for the most part confirm the correctness of the preceding representations. By hardening portions of the cord by means of certain chemical agents, and placing exceedingly fine sections of the hardened parts in a saturated solution of carmine in spirit, the component parts of the cord are rendered more readily distinguishable from each other; the grey matter becomes clear; the nerve filaments are rendered more distinctly visible, their edges becoming sharper; the multipolar cells are coloured red; the axis cylinder of the nerve tubules is also coloured red, but not their outer walls, which remain white; the connective tissue and the blood-vessels are also coloured red, the latter being distinguished from nerve filaments by strongly marked edges.

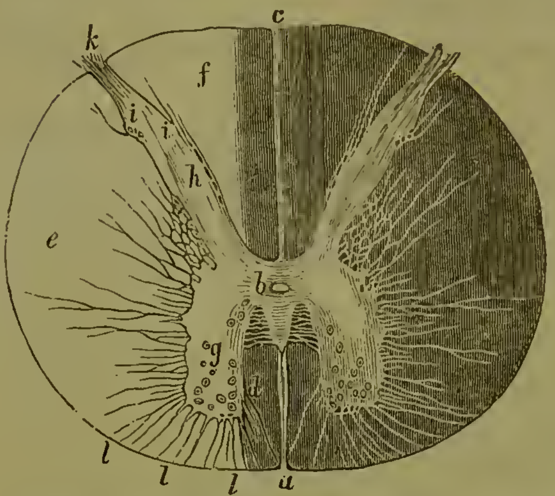
When very fine sections thus prepared are brought under the microscope and magnified one hundred times, both horns of grey matter, according to this investigator, are seen to abound with multipolar cells; those in the anterior horn, however, being decidedly the largest and most abundant.

The great facts established by these researches are, that the multipolar cells, on the one hand, give off filaments which pass directly into the nerve roots; while the nerve roots, in their turn, enter into the cells. "In a very successful preparation," says the author, "from which a drawing was taken, the passage of the nerve filaments into the cells was clear to demonstration, while the origin of the anterior nerve roots from cells was so evident as to leave no room for doubt on the subject."

As far as regards the fibres of the anterior root, he considers it as demonstrated that they take their origin in the multipolar cells of the grey matter of the anterior horn.

With reference to the fibres of the posterior root, he states, in accordance with preceding observations, that they consist of two sets; one of which, on entering the cord, immediately curves upwards, proceeds to the longitudinal columns of the cord, and continues to ascend with them to the brain; while the other set run transversely across the longitudinal fibres, and penetrate the cells of the posterior horn, in which they are lost. Fig. 106 represents two roots which, in this manner, take opposite directions.

Fig. 106.



Transverse section of human spinal cord, close to the third and fourth cervical nerves; magnified ten diameters (from *Stilling*). *f*, posterior columns; *i i*, gelatinous substance of the posterior horn; *k*, posterior root; *l*, supposed anterior roots; *a*, anterior fissure; *c*, posterior fissure; *b*, grey commissure, in which a canal is contained, which, according to this writer, extends through the length of the cord; *g*, anterior horn of grey matter containing caudate vesicles; *e*, antero-lateral column (from *k* to *a*).

He further calls attention to another set of fibres contained in the posterior horn, which are more slender and delicate than the white ascending fibres, which take a longitudinal direction, and which he regards as fibres of communication particularly connecting with one another the series of groups of cells situated at different heights of the spinal column. It has been long known that the cord contains certain longitudinal fibres distinct from those of the nerve roots, the office of which remains to be interpreted.

From the whole of these researches it may be inferred—

1. That each nerve root, on reaching the cord, definitely divides into two fasciculi, one of which enters into the anterior and posterior horns of the grey matter respectively, where it is anatomically connected with the multipolar cells in the manner above described.

2. That the second fasciculus in each case becomes continuous with the longitudinal fibres of the cord, and so ascends to the brain.

The root fibres which go to the posterior horn are named, from the course which the currents take, the incident nerve fibres; or, from their physiological signification, the excitor fibres (excito-motory of Marshall Hall). The fibres of the anterior root, emerging from the anterior horn, are called, in accordance with the course of the current, reflex. These two sets of fibres, together with the grey matter with which they unite, constitute the true spinal system.

The fibres of the posterior root which join with the longitudinal fibres of the cord, and so ascend to the brain, are called sensory fibres. The fibres of the anterior root, which also join the longitudinal fibres of the cord, and in like manner ascend to the brain, are named the volitional fibres.

On evidence hereafter to be given, it is believed that the incident and reflex fibres, with their central grey matter, form together one great motor system—the system, that is to say, of excited motion without consciousness.

On similar conclusive evidence it is believed that the sensory fibres which go to the convolutions of the brain, the organ of consciousness, are for the conduction of sensation.

On evidence alike convincing it is believed that the volitional fibres communicating with the brain are for the conduction of volition—the stimulus essential to the action of another great system of motion, to which consciousness is indispensable — the system of voluntary motion.

Such are the conclusions to which a careful consideration of the whole of this involved question, in its anatomical, physiological, and pathological aspects, clearly leads. The more the evidence on which these views rest is examined, the more consistent and satisfactory they appear. They give a significance to every part of this wonderful apparatus, and they in some degree enable us to understand its action.

CHAPTER XXV.

FUNCTIONS OF THE SPINAL CORD.

Seat of a peculiar nervous force—Proofs—Two-fold action of the excito-motory power—Incident and reflex—Examples—Explains the most complex actions of the body—Tone of the muscular system.

The complex structure of the spinal cord and the obvious difference of its organisation from that of the ganglionic and cerebral systems, naturally suggested the inference that it performs some distinct and important office, but it was long before anything was ascertained of the true nature of its action. The researches of modern science, based on exact observation and experiment, have led to the discovery that it is the seat of a peculiar nervous force, governing an extensive and most interesting class of vital phenomena, of which before this discovery the physiologist could give no intelligible account.

An experiment is an interrogation put to nature, to which if rational in itself, and wisely asked, she will return a distinct and true answer. To some questions thus addressed to her by experimentalists of recent times, she has responded as to friends; and it is on the answers they have received that the real knowledge of the nervous system in general, and of the spinal cord in particular, is mainly founded.

The plan on which the animal body is constructed is that of binding up different structures, performing widely different offices in one common mass. It is impossible to arrive at a knowledge of any distinct function without separating such a mass into its several constituents, and examining each apart from the rest. The difficulty of doing this constitutes the main obstacle to the advancement of physiology. When this isolation has been successfully accomplished in any instance, a single well-considered, well-devised experiment is sometimes sufficient to obtain a decisive answer to the interrogation.

Such an answer has been obtained to several highly important questions relative to the functions of the spinal cord.

If the brain be entirely removed from the body, an animal retains the power of producing definite and combined muscular movements when the external surface of the skin is touched. If the spinal cord be destroyed this power instantly ceases. It is concluded, therefore, that this power resides in the spinal cord.

When the spinal cord is divided, the influence of the brain below the section is wholly cut off, because the cerebral fibres are severed; while the spinal cord below the division and the spinal fibres attached to it remain entire. In every instance of this kind the functions of the brain are annihilated, but those of the spinal cord remain unimpaired; no indication of sensation or voluntary motion can be elicited, but irritation of the skin excites decided and often violent contraction of the voluntary muscles.

Individual segments of the cord are endowed with the same power. If the cord be cut through in the neck, or in the back, irritation of the skin in either part produces convulsive action in the muscles of that part alone.

Paralysis of the lower part of the body instantly follows a division of the lower part of the cord; but if the skin covering the heel of a leg thus paralysed be irritated, the toes are extended, the heel is raised, and both legs are moved. In parts capable of this combined action, so completely is all sensibility lost, that the legs may be cut off, without the animal attempting the least motion, or indicating by any other means the slightest degree of sensation. The same results are obtained if the head be removed from the body.

A horse received a violent blow on the fore-part of the head, immediately over the anterior lobes of the brain; it instantly fell, and lay perfectly motionless. After a short time it began to breathe, and continued to breathe freely by the diaphragm. When lacerated on the face, or pinched in any other part of the surface of the body, it remained totally motionless, manifesting no indication of sensation or volition. But when the eyelash was touched with a straw, the eyelid was forcibly closed; when the cornea was touched the eyeball revolved outwards, and when another part of the skin was touched, the tail was raised. On destroying the spinal cord all these motions instantly ceased.

Here a blow annihilated the cerebral functions, but the spinal still remained. Deep lacerations produced no evidence of the former; the touch of a straw induced a full manifestation of the latter. The destruction of the cord removed all trace of the spinal phenomena.

In the human body disease often performs a nicer dissection than the most skilful anatomist can accomplish, and separates the cerebral from the spinal functions more definitely and completely than the best experimentalist can do. In apoplexy, when a blood-vessel bursts, and a stream of blood is forced into the soft and tender substance of the brain, the cerebral fibres are torn asunder, and of course all communication is immediately cut off between the brain and those parts of the body to which the lacerated fibres were distributed. Under these circumstances, when one side of the body is senseless and powerless, as in hemeplegia, or when all the lower part of the body is paralysed, as in paraplegia, if the legs are pinched, and especially if the sole of the foot is tickled, the legs are contracted with great force, though the patient is wholly unconscious of the motion.

It is clear, then, that there is inherent in the spinal cord a power distinct from that of the brain, and independent of it, capable of producing motions as complex in their combinations and as definite in their object, as any which are the undoubted results of consciousness.

This power has received the name of excito-motory, because its action is always an excited one, and because the result of the action is invariably the production of muscular motion.

The action is two-fold, consisting of the transmission of two nervous currents in opposite directions: one centripetal, from the surface of the body, or of the particular organ excited, to the centre; and the other centrifugal from the centre back to the organ.

The carbonic acid of the venous blood coming in contact with the nerve fibres expanded on the surface of the air-cells of the lungs produces on them a certain effect, called an impression. This impression is transmitted to the nervous centre, the spinal cord, on the reception of which the latter sends out a force to the muscles of respiration which causes them to contract, the result of their contraction is the expansion of the chest.

Here there are two nervous currents proceeding in definite but opposite directions, the one from the organ impressed to the centre, and the other from the centre to the muscles which are to be excited. The fibres which transmit the first are termed the incident fibres, because the impression falls upon them; the fibres which transmit the second are termed the reflex, because the nervous force sent from the centre is said to be reflected from it to the muscles.

The transmission then of an impression by incident fibres to a nervous centre, and the reflection of a nervous force from the centre to a muscle, or a group of muscles, causing them to contract, and so to produce a definite motion for the accomplishment of a definite purpose, constitutes an excito-motory action. It takes place in every instance in which an excito-motory function is exercised. For the sake of brevity it is often called, in physiological language, reflex action. It is an action unceasingly pervading the animal frame.

That muscular contraction caused by an influence derived from nerves, is not the direct result of the reaction of nerves and muscles on each other, but that the irritation is first conveyed to a nervous centre, and then reflected back to the muscles, did not altogether escape the observation of the earlier physiologists. Among others, Whytt, Haller, Prochaska, and Cullen have recorded evidence that reflex action was not unknown to them. But it is to Dr. Marshall Hall that the honour is due of having deduced the generalization in its full completeness from original observations and experiments, and of having clearly expounded the nature and determined the extent of the phenomena. In prosecuting an experimental inquiry respecting the circulation of the blood, he one day, chanced to observe a remarkable phenomenon, that the separated tail of the eft he was examining, moved on being irritated by the point of the scalpel. Meditating long on this incident, and believing that it indicated the action of some principle not hitherto elucidated, he instituted a series of experiments and observations for the purpose of discovering it. About the same time similar researches were made in Germany by Professor Müller without any knowledge of what had been done by Marshall Hall, who, it is admitted, had the priority. By different routes both physiologists arrived at nearly the same point. There is a perfect coincidence in their facts, but a considerable difference in their interpretation of them.

Dr. Hall's conclusions may be comprised in the following summary:—

1. "That there exists a true spinal cord, physiologically and anatomically distinct from that portion of the cord which is strictly an appendage of the brain.

2. "That there is a system of nerves physiologically distinct from the sentient and voluntary nerves, called excito-motory nerves, consisting of *incident* nerves, which arise from the skin and certain mucous membranes, and of *reflex* nerves, which end in the voluntary muscles. These parts collectively, that is to say, the true spinal cord and the excito-motory nerves, constitute the true spinal system.

3. "That currents of nervous influence may be excited passing

upwards from the skin to the spinal centre, and downwards from the spinal centre to the muscles, through the medium of the incident and reflex nervous fibres."

If the fundamental doctrine of Bell be true, that each primitive nerve fibre has the power of carrying an impression in one direction only—the fibre of sensation from the skin to the brain, the fibre of motion from the brain to the muscle—there must be a system of incident and reflex nerves as distinct from the cerebral nerves of sensation and voluntary motion as their centre is from that of the cerebrum. There must be an anatomical channel for this physiological action. It would be directly opposed to all which modern science has established respecting the nervous system to conceive that in any part of it two functions can coexist in one individual fibre. Difference of function implies difference of structure; the difference in the physiology implies a corresponding difference in the anatomy.

It is highly probable that the anatomical channels by which the incident and reflex functions are performed are the fibres first traced and described by Mr. Grainger, of which a full account has already been given. The proof that the two roots of the compound spinal nerves perform two separate functions has been established beyond all controversy by Bell. The demonstration by Mr. Grainger that there are really four roots instead of two, justifies the inference that there are four functions in operation, of which the incident and reflex form two. The anatomy relative to this point is not called in question; and though there is not a universal consent as to the interpretation of it, yet some of the most distinguished physiologists both in England and on the Continent have received the view here given as the most probable.

It must be conceived, then, that together with all the common nerves of sensation and volition in every part of the animal frame, there are bound up two other orders of fibres—the incident and the reflex, by means of which all the excited actions of the body are performed.

The incident fibres, as already stated, always centripetal, are expanded on the external and internal surfaces of the body; on the skin its external, on the mucous membrane its internal surface. An external body, a stimulus, impresses these expanded incident fibres: the fibres convey the impression to the centre; the centre excites and combines certain muscles with simultaneous action, and a definite, sometimes an exceedingly complicated action—a reflex action, is the result.

These excited actions form a class of their own. They may be comprised in the following enumeration:—

Those by which the complicated movements of deglutition and of respiration are performed.

Those by which certain passages to the interior of the body are closed against the entrance of particular substances, as the firm closure of the glottis on the inspiration of carbonic acid gas.

By which other passages are opened for the entrance of certain substances into internal receptacles, as the stomach, the intestines, the gall bladder, the urinary bladder, the rectum, the uterus, and so on.

By which these receptacles are closed so as to retain within them the substances they receive for a given time.

By which these receptacles are again opened so as to permit their contents to pass out of them.

By which such contents are actually expelled either from the receptacles or from the body.

These actions include, more especially, the muscular movements by which masses of matter are introduced into the system and expelled from it; by which food is conveyed to the stomach, and air to the lungs; by which these substances, the crude materials of nutrition, are transmitted to their appropriate receptacles, and retained there to undergo the necessary changes; and by which, when these have been accomplished, the new-formed substances which are useful are sent out for distribution to the system, and those which are useless or noxious are expelled from the body.

Decisive experiments, the results of some of which have been stated, prove that the spinal centre is the generator of the nervous force by which the muscles that perform this entire class of motions derive their motive power. This centre, therefore, in the language of Dr. Hall, presides over ingestion and exclusion, over retention and egestion; consequently its influence is exerted upon the muscles which belong to the entrances and outlets of the animal frame, or in other words, upon the sphincters, the muscles of deglutition and of respiration.

The guardian thus of all the entrances and exits of the animal frame, this centre, by one set of excitor nerves (the trifacial), guards the eye, the nostril, the ear, the fauces; by another (the pneumo-gastric) it guards the larynx, the bronchia, the cardia, the ureter, and the gall-duct; by a third (the spinal) it guards the rectum, the bladder, the uterus, and so on.

With each part of the series of excitor nerves there is connected a corresponding set of motor nerves—the motor to produce the motions required, the excitor, under the influence of the nervous centre, to excite and control the actions.

With this apparatus it is easy to understand how the most complex motions of the body may be performed; how deglutition, for example, may be so; how in the act of swallowing, when the morsel reaches the base of the tongue and fauces, the pharynx by one movement is raised, and by another entirely different movement is expanded to receive the food; how the larynx, which stands immediately before the pharynx, is at the same time firmly closed to prevent the food from passing into the lungs instead of the stomach; how, the instant the morsel is transmitted over the glottis and touches the pharynx, this organ grasps it, contracts forcibly upon it, and propels it into the œsophagus; and how the œsophagus, in like manner, contracts upon it and forces it downwards, while the cardia, the guardian of the stomach, usually firmly closed, opens to give it free passage into the stomach.

Here a multitude of muscles, differently constructed, occupying different situations, performing different actions, some the direct reverse of others, are made to produce combined, successive, co-ordinated movements for the accomplishment of a definite purpose. In the fulfilment of this purpose every one of these muscles must act at a given time, with a certain force, in a fixed order; failure of any one of these muscles, in any one of these particulars, may disturb the function, may defeat it altogether, may prove instantly fatal. Daily, hourly, these motions take place without the slightest consciousness on the part of the individual that any such motions are going on within him. That they should go on with such regularity, in such harmony, appears inexplicable. The mystery is solved in part on the supposition that there is established an apparatus of excitor and motor nerves in connection with a corresponding apparatus of muscles; and that the simple contact of a physical agent—a morsel of food, a drop of water—with the excitor or incident nerves suffices to set the rest of the mechanism in action, the incidental nerve conveying a definite impression to its nervous centre, and the nervous centre sending out by a reflex nerve a force which stimulates the muscles with which it is in relation to a definite series of motions.

There is still another function performed by the spinal centre essential to the well-being of animal life; it is the primary source of what is called the tone of the muscular system.

In health the muscles are maintained in a certain state of permanent contraction, quite different from the occasional active contractions of the voluntary muscles and the rhythmetrical contractions of the involuntary muscles. It is a state common to the entire muscular system, in which especially the physical properties of the muscular tissue are maintained in their due force and balance; when, if a muscle be touched, it offers a certain degree of resistance; if it be removed from its natural position, it is drawn back again of its own accord with a certain recoil; and if it be stimulated, it contracts with a certain degree of energy: a state in which the physical properties of firmness and elasticity, together with the vital property of excitability, are maintained in their due force and balance. If the spinal cord be destroyed, all these properties are instantly lost. The muscles become lax and flaccid; they lose their resiliency, and no amount of stimulus can animate them to the slightest degree of contraction. These states coexist or cease with the integrity of the spinal cord: the conclusion is that they have their origin in it, and depend upon it.

Such are the main functions performed by the spinal centre, which in their full extent comprehend all the actions concerned in the preservation of the individual and the perpetuation of the species.

It has been before observed that the functions of the ganglionic are closely allied to those of the spinal centre. They are, indeed, as far at least as regards their modes of action, identical. In both all the actions are insensible, involuntary, automatic; in both they require for their manifestation the presence of an external agent or stimulus; in both they are necessary, definite, and produce a definite result, however complex the means of accomplishing it. The nature of the action of both centres is, therefore, probably the same, but they fulfil different purposes. There is a division of labour in the economy. To the ganglionic centre is assigned one part of the work, to the spinal centre another. The spinal centre deals with the introduction into the system of masses of matter; the ganglionic centre operates upon the individual particles. The spinal centre is the medium by which the raw materials necessary for carrying on the various processes of life are conveyed into the body. The ganglionic centre operates on these masses, decomposes them, recombines them, and distributes them in a due state of preparation to the several organs in which they are to be used up and appropriated for the special purposes of the economy.

CHAPTER XXVI.

STRUCTURE OF SPINAL NERVES.

It has been shown (Fig. 105) that each spinal nerve consists of two roots, the anterior and posterior, which arise by delicate filaments from their respective lateral fissures on the surface of the cord. The roots as they spring from the cord lie in the arachnoid pouches, surrounded by the arachnoid fluid, the ligamentum denticulatum intervening between them (Fig. 103).

The posterior roots arise in a regular series along the sides of the cord, converge towards its sheath, and being collected together, are surrounded by the sheath, and just at the point where they are united to this envelope they form a ganglion.

The filaments of the anterior roots arise in a similar manner, but somewhat less regularly, and from a broader surface; converge towards the sheath in which they are enveloped, and then join the posterior roots, close to the ganglion, which, however, they do not enter by a single fibre, but merely lie in contact with it (Fig. 105). Immediately after they pass the ganglion the two roots coalesce to form the nerves; so that each nerve is composed of both roots intermingled together.

The nerve-roots are capable of being traced from the surface into the interior of the cord (Fig. 106). Minute dissection shows that each root consists of two roots, one of which, ascending, proceeds along the white column of the cord to the brain; while the other, taking a transverse direction, nearly at right angles with the cord itself, pursues its course to the grey matter in the interior of the cord.

Every spinal nerve (including also certain cerebral nerves) being formed in the same manner, must necessarily present characters common to the class. They have all double roots; they have all a similar origin and distribution; they all go out in regular succession to every part of the body, so that there is not a tissue or a surface to which they do not give fibres in greater or less abundance; they all exercise the same function, and they are common to every class of animal, from the worm to the elephant, from the creeping thing to man.

From their perfect regularity they have been termed the regular or symmetrical system of nerves. They are commonly enumerated as thirty-one pairs, which take their name from the vertebræ under which they pass, and hence there are reckoned seven cervical, twelve dorsal, five lumbar, and five sacral; but these make only twenty-nine pairs; two more are added for reasons immediately to be stated.

Functions of Spinal Nerves.—Every spinal nerve containing both roots is a compound nerve, and has a double function. The posterior root is for one office, and the anterior for another. The distinct function of each is now clearly ascertained, and this is one of the most important facts in physiology. It is proved, by indubitable evidence, that the posterior root is for the communication of sensation, and the anterior for the communication of motion. This is demonstrated—1. By the effects of disease. In paralysis one of the functions of a spinal nerve is sometimes lost, while the other is preserved; sensation is destroyed while the power of motion remains undiminished; even an entire limb may be motionless while its feeling continues perfect. 2. By direct experiment. On irritating the posterior roots in a living animal, no motion is produced; but the animal gives unequivocal indications of feeling pain. On the other hand, if the anterior roots are irritated, no sign of feeling is usually excited, but every touch is followed by a muscular motion as distinct as that produced by striking the keys of a piano. Occasionally, indeed, some degree of feeling is elicited, which is explained by filaments from the posterior entering into the anterior root. Further, when the whole of the anterior roots going to a limb, the leg for example, are divided, the animal loses all power over the leg, which retains its sensibility undiminished; but when, on the contrary, the posterior roots are divided, the power of motion continues, but the sensibility is lost.

These observations and experiments place beyond all doubt the fact that the nerves of sensation and of motion are distinct from each other, and that the anterior roots are the source of motion and the posterior of sensation.

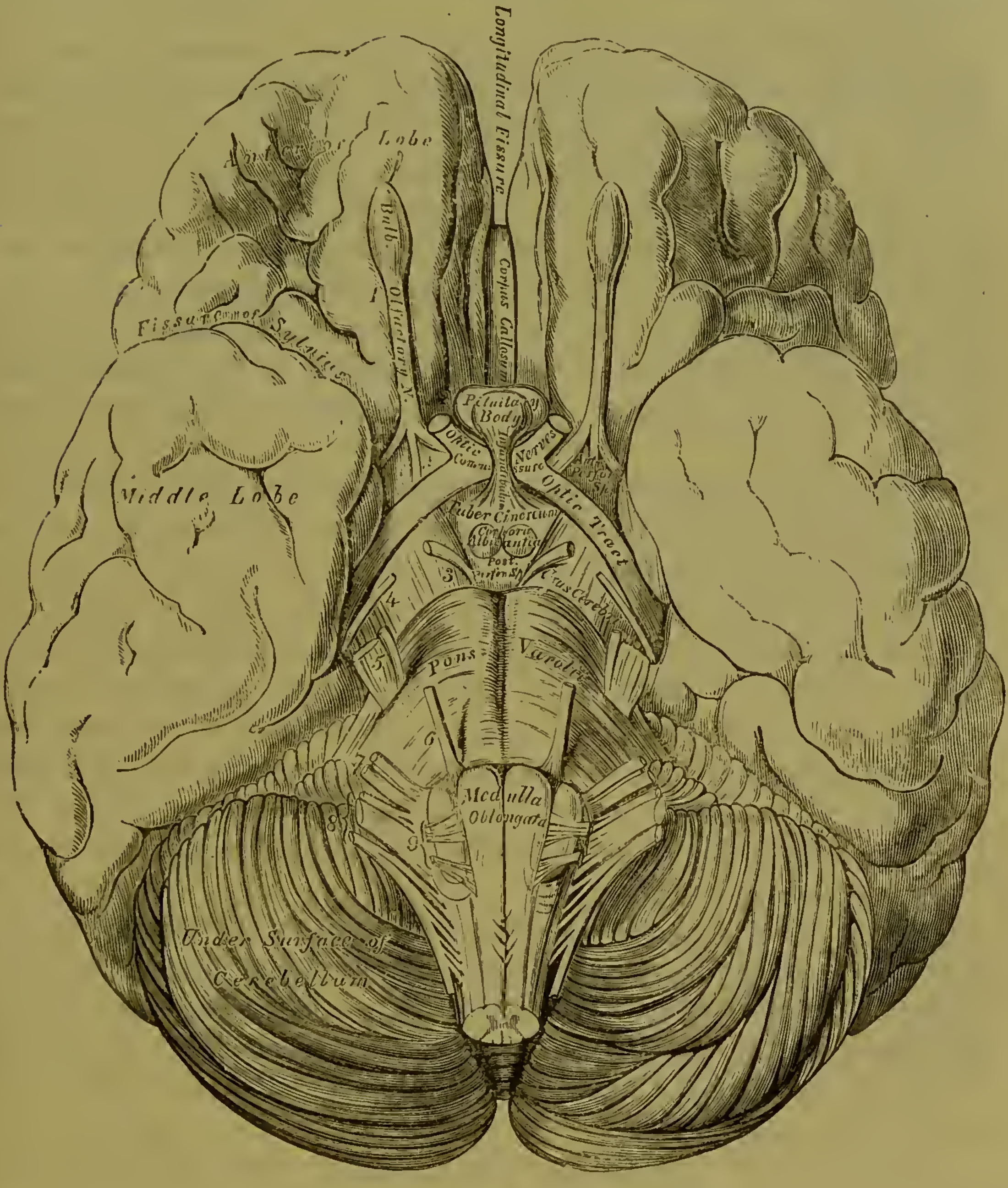
It is impossible to attain evidence thus positive of the functions of the roots after they penetrate the surface of the cord, because there are no known means of isolating the ascending filaments, which go to the brain, from the transverse filaments, which are lost in its interior grey matter, but the reasons have been stated which render it highly probable that the ascending fibres are for volition, and the transverse for reflex action.

Cerebral Nerves.—The cerebral nerves, as their name imports, take their origin from the brain. They are commonly said to be ten in number, and they are enumerated in the order in which they proceed from the brain.

1. The first pair, the olfactory, arise from the striated bodies (Fig. 107, 1), and are distributed to the mucous membrane of the nose, there forming the organ of smell.

2. The second pair, the optic, arise from the optic thalami and tubercles (Fig. 107, 2), advance into the orbits, penetrate the eyeballs, and expand into the retinæ, and so constitute the organ of vision.

Fig. 107.



Base of the brain.

3. The third pair, the motores occuli, or motors of the eye, arise from the crura cerebri, between the corpora albicantia and the pons varolii (Fig. 107, 3), and passing into the orbits, are distributed to most of the muscles that move the eyeballs.

4. The fourth pair, trochleares or pathetici, arise from the optic tubercles (corpora quadrigemina) (Fig. 107, 4), pass round the crura cerebri, penetrate the orbit, and are entirely spent upon the two muscles, the oblique, which roll the ball of the eye.

5. The fifth pair, trifacial, arise from the medulla oblongata, pass through the pons varolii (Fig. 107, 5), and form three large branches, whence their name. It has two roots, like a spinal nerve, and on one of them is placed a large ganglion, termed the ophthalmic or lenticular, from its shape. This nerve is mainly distributed to the head and face.

6. The sixth pair, the abductors, arise from the commencement of the medulla oblongata (Fig. 107, 6), and, like the fourth, are distributed entirely to certain muscles of the eyeball, the abductors, the action of which is to draw the eye from the nose towards the temples.

7. The seventh pair arise from the medulla oblongata (Fig. 107, 7), and consist of two portions, one termed the portio mollis, and the other the portio dura. The first is the auditory nerve, and is distributed entirely to the internal parts of the ear, forming the organ of hearing. The second is a motor nerve, and is distributed to the muscles of the face; hence it is often called the facial nerve (Fig. 107, 7).

8. The eighth pair arise from the medulla oblongata at the sides of the olives (Fig. 107, 8), and consist of two portions, termed the glosso-pharyngeal and the vagus.

The glosso-pharyngeal, which is often numbered separately, and termed the ninth pair, is spent chiefly upon the pharynx and the tongue; hence its name from *γλωσσα*, a tongue, and *φερειν*, to convey, because the pharynx conveys the food into the stomach.

The vagus, so termed from its wandering course, is also called the pneumo-gastric, from *πνευμων*, a lung, and *γαστηρ*, a stomach, because, widely spread as are its branches, its principal distribution is to the lungs and stomach.

9. The ninth pair, the linguales, from lingua, a tongue, is also called hypoglossal, from *υπο*, under, and *γλωσσα*, a tongue, because it is distributed principally to the under part, that is, the muscles of the tongue. Both pairs arise from the sides of the pyramids (Fig. 107, 9), on the forepart of the medulla oblongata, and are distributed as indicated by the name.

10. The tenth pair, the accessorii, because they are regarded as appendages to the eighth pair, arise from the upper part of the spinal cord, and are distributed to the muscles of the shoulder.

The Cerebral Nerves.—The ten so-called cerebral nerves just enumerated consist of two classes, the true cerebral and the spinal. The true cerebral nerves are those which arise from the cerebrum by single roots, and have no ganglion. They are simple nerves, and are seven in number, namely, the olfactory, the optic, the motores occuli, the trochleares, the abductors, the portio dura and mollis of the seventh pair, and the linguales. The remaining three, the trifacial, the vagus and the accessory have double roots. They are therefore compound nerves, and, though arising in the cerebrum, must be regarded as essentially spinal nerves. There is good reason to believe that the separate motor nerves, the third, fourth, sixth, and portio dura of the seventh are typically anterior roots, the portio major of the fifth being their posterior roots.

A very remarkable and interesting distinction has been drawn by Sir Charles Bell between these two classes of nerves. It has been stated that the regular, symmetrical, or spinal nerves, are common to all animals in which a nervous system exists at all, from the worm up to man. This, therefore, must be regarded as the original system. The others are superadded, to communicate new functions as additional organs are multiplied in the ascending scale. Universally the symmetrical system communicates sensation and voluntary motion, and, in proportion as new endowments are given beyond these primary faculties, the superadded nerves increase in number and complexity in the entire animal series.

"When an animal is endowed with mere sensation and locomotion," says Sir Charles Bell, "when there is no central organ of circulation, no organ of respiration but what is diffused over the frame, the nerves are extremely simple." They consist, as has been shown, of two cords running the length of the body, with branches going off laterally to the several divisions of the frame. Hence there is no intricacy, no double supply of nerves; each portion of the frame has an equal supply. The central line of connection is sufficient to combine the action of the muscles, and to give them the concatenation necessary to locomotion. There is really the same uniform and symmetrical system in the human body as in the worm, but it is obscured by the variety of superadded nerves. These nerves belong to organs which gradually accumulate in the ascending series, until we arrive at the accumulation in the human frame. When these superadded nerves are separated, the original system in its simple constitution is presented even in the human being.

In the most highly organised body its several organs are supplied with nerves according to the offices they perform. No organ which possesses only one endowment has more than one nerve, however exquisite may be its sense or action. If two nerves coming from different sources are directed to one point, this is a certain sign that it performs a double function. If an organ has many distinct nerves, it has the power of exercising so many distinct offices, or of entering into so many different combinations. Nerves are not supplied to an organ from different sources to give it an accumulation of nervous power, as was long supposed by anatomists, but to give it new powers. Take, for example, the mouth. To all animals some process of respiration is necessary, but this is not in all carried on by means of the mouth. In those animals that do not use the mouth in breathing, it has only one function to perform, that of taking in food, and, for this a single nerve sufficing, it has only one nerve. In the same way, in all animals whose face and nostrils have no complexity of relation, those parts have only a single nerve. But, when the anatomist employs many weeks to dissect and disentangle the nerves of the throat and palate in the human subject, he finds at length that he has exhibited the branches of five different trunks of nerves. There is no clue to the labyrinth till he considers the multiplied offices of the mouth of man. It is a pneumatic organ; it is a manducatory machine; it is an instrument of voice; it is an instrument of articulate speech; it is an instrument of singing; it is an organ of taste endowed with exquisite feeling. It would indeed be matter of surprise if the same nerve served for the action of gnawing and feeding in the lower animals of simple structure, and also for the governance of those complicated operations which serve to interpret the wants and sentiments of man.

So with respect to the tongue, which is supplied with nerves from three different sources: it is an organ essential to the processes of mastication and deglutition; it is an organ of touch; it is an organ of taste; and it is *the* organ of articulate speech, by which man communicates and combines with man, and without which he would have been incapable of civilisation and progress.

THE INDIVIDUAL CEREBRAL NERVES.—Three of these nerves, the olfactory, the optic, and the portio mollis of the seventh are nerves of special sense. Three others, the motores occuli, the trochleares, and the abducentes, are devoted to the motions of the eyeball. It is remarkable that the six muscles which produce the varied movements of the eye derive their motor power from three different sources, when all of them are within the reach of branches from a single nerve. The reason seems to be that the action of some of these muscles is directly opposed to that of others; and it appears to be a general rule that when muscles are required to act in opposition to each other, the antagonists are supplied by nerves derived from different sources.

THE THIRD NERVE, OR THE MOTORES OCCULI.—The motions of the iris are produced and governed by filaments derived from the third nerve. The movements of this contractile curtain, suspended between the retina and the external light, in order to regulate the quantity of light admitted to this exquisitely-sensitive nervous expansion, appear to be of a reflex nature. The stimulus of light on the retina is conveyed by the optic nerve to the brain, which, on receiving the impression, sends back by means of the third nerve its commands to the muscles of the iris so to contract or dilate its aperture as to regulate the due admission of light to the eye.

The Fifth, or Trifacial Nerve.—Of the two branches of which this nerve is composed, one constitutes the portio major, and which, having a ganglion upon it, corresponds to the posterior root of a spinal nerve. It is purely sensitive, and communicates common sensation to the head and face. The minor portion corresponds to the anterior roots of the spinal nerves, but it also receives a branch, the semilunar ganglion, and so becomes a compound nerve of motion and sensation, supplying sentient parts, as the side of the head, the skin of the chin, the teeth, &c., and muscles, as the mylo-hyoid, &c., has no ganglion, and therefore corresponds to the anterior root of a spinal nerve. It is principally motor. It gives motor power to the large muscles that move the lower jaw; that is, to the muscles of mastication. To excite the powerful contractions necessary in this operation is its chief office, though it would appear from several experiments that it is also in some degree sensitive, probably deriving sensitive fibres from its other portion.

Numerous observations and experiments prove that the two portions of this nerve exercise the functions here assigned to them. If its larger or ganglionic portion is irritated in a living animal, the slightest touch excites acute pain, but no motion; while if the smaller branch is irritated, violent contractions are produced in all the muscles of mastication, without the smallest indication of feeling.

Comparative anatomy shows that in all classes of animals, from the lowest to the highest, wherever there is any trace of this nerve, it is the source of feeling in all parts corresponding to the head and face. "If," says Sir Charles Bell, "a feeler of any kind project from the head of an animal, whether the antenna of a lobster, or the trunk of an elephant, it is a branch of this nerve which supplies the member." In the human subject, a branch of this nerve, distributed to the lower jaw, takes its course under the roots of the teeth. A grinder of the lower jaw was extracted, and some of these nerve-fibres were injured. Immediately after the operation, on putting a tumbler of water to his lips, the patient said, "Why have you given me a broken glass?" The glass was entire, but sensation in one half of the lower lip was gone, and this gave the impression that only half the glass was put to the lip.

A gentleman falling, a sharp point entered his cheek, and divided a branch of this nerve (the infraorbitar) that supplies the upper lip. Sensation was lost, while the power of motion remained, and in this, as in the former case, when a cup was put to the lip, it appeared to be broken, and for the same reason—that part of the cup which was placed in contact with the insensible portion of the lip could not be felt, and therefore gave the impression of being broken off.

Tumors sometimes press on the branches of this nerve, in which case the sensibility of all the parts supplied by it is entirely lost, while their motion remains unimpaired.

But the ganglionic portion of the trifacial nerve, though principally devoted to the communication of sensation, is not limited to that office. It exercises an important influence over the movements of all the parts to which it imparts sensibility: first, by giving that sensibility to the muscles themselves; secondly, by conveying to the centre a perception of the position and actual condition of the muscles, without a knowledge of which the mind would be incapable of influencing and controlling them in the actions of volition; and thirdly, by maintaining their power of reflex action; that is, of conveying impressions, by their peripheral expansions, to the nervous centres, to be thence reflected. So, when this nerve is divided, irritation of the conjunctiva produces no closure of the eye; mechanical irritation of the nose excites no sneezing; the application of sapid substances to the tongue produces no flow of saliva; reflex actions constantly performed in the perfect state of the nerve.

Lastly, the sensitive portion of this nerve influences materially the organs of sense, inasmuch as it communicates to them their common sensibility, while they derive their peculiar sensations through their several special nerves. It is even conceived that, by one of its branches, it is itself a nerve of special sense; that by its lingual, or gustatory division, it endows the tongue with the sense of taste. It seems scarcely probable that a nerve of common sensation should also be a nerve of special sense, but this subject will be again referred to immediately.

PORTIO DURA OF THE SEVENTH PAIR, OR FACIAL NERVE.—This is the special motor nerve of all the muscles of the face, with the exception of those of mastication. Division of its trunk paralyses the whole of these muscles; division of the branch going to one side of the face paralyses all the muscles on that side; the muscles on the side on which the nerve remains entire retaining their natural action.

Numerous observations illustrate the effects of injury of this nerve.

A pistol-ball entered the ear and tore across the portio dura at its root. All motion on that side of the face ceased, but its sensibility remained undiminished.

A man was wounded by the horn of an ox. The point tore across the portio dura. That side of the face immediately lost all motion; the eyelid remained open; the nostril was motionless; and the mouth was drawn to the opposite side, from the force of the muscles on that, the uninjured side; the sensibility remained perfect.

The portio dura was divided in the removal of a tumor behind the ear. The immediate effect was horrible distortion of the face by the prevailing action of the muscles of the opposite side, but without the loss of sensibility.

It has been stated that if a feeler or antenna be simply for sensation, it has only one nerve; but that when motion is added two nerves are supplied. It was suggested that, if this theory be true, the trunk of an elephant, which is not merely a feeler, but also an important instrument of respiration, should have two nerves. "From the great power which the elephant has over his trunk," says Mr. Shaw, "I was certain that there must be large nerves runing to it, similar to those which supply the fingers in man; but as the proboscis forms an important part in the respiratory process in this animal, I thought that the dissection of it there would be the most direct proof of the accuracy or fallacy of Mr. Bell's opinions on the subject of the portio dura. On examination it was found that two large nerves take their course along the trunk, one from the portio dura, and the other, of nearly equal size, from the portio major of the fifth.

The face is the natural organ of expression. The muscles which give that expression are animated and controlled by the facial nerve, but they acquire their sensibility only through the fifth nerve, and they retain their power of expression only as long as they maintain their muscular sensibility. For the power of expression, therefore, both nerves must act in unison.

A knowledge of the separate and combined functions of these nerves is of the highest practical importance. Divide the portio dura, paralysis of all the parts supplied by the divided branches inevitably follows. Divide the portio major of the trifacial nerve, the loss of sensibility of all the parts upon which it is spent equally follows. A half-informed surgeon knows that the eyelids are abundantly supplied by branches of the fifth nerve. He trusts to these nerves to supply motor power to the eyelids, but these fibres give sensation only, not motion. In opening an abscess or removing a tumor, he unhesitatingly divides the fibres that alone give motion, namely, the branches of the portio dura. Henceforward the eyelids stand open, the eye is permanently uncovered, the cornea becomes opaque, and the vision of the eye is lost.

A knowledge of the sources of expression is highly interesting to the mother and the nurse. Watch the breathing of an infant in disease. It has recovered, suppose, from a fit in which there was deep insensibility. Hope revives, but the powers do not rally. There is no returning fit, but there is no increasing sensibility; there is no reanimation of the muscles. On the contrary, insensibility and loss of motion steal over the frame. Every act of the hurried respiration is attended with twitchings of the muscles of the nostrils, and of that muscle of the cheek which makes the dimple in smiling. The child cannot recover. All but the respiratory muscles have lost their power. These are the last to die; and the state of these indicates too plainly that actual death approaches.

There is a state of the lungs in which the patient is in imminent danger, unmarked by pain or by difficult motion of the chest. There is nothing to be seen, perhaps, but a more hurried respiration than natural, a twitching of the muscles of the face, a certain undulation of the nostrils, a constrained motion of the lips, a change of voice—a state often occurring after severe accidents, gun-shot wounds, great surgical operations, and in an advanced stage of fever, especially where inflammation of the mucous membrane of the lungs has been slowly stealing on. Slight as these symptoms may appear to the inexperienced eye, they indicate a mortal condition of the patient.

THE GLOSSO-PHARYNGEAL NERVE.—The glosso-pharyngeal, vagus, and spinal accessory nerves, are so intimately connected together, that they are commonly enumerated as branches of one nerve. The glosso-pharyngeal has a double root, one answering to the posterior, the other to the anterior root of a spinal nerve. So the whole trunk of the vagus, as it passes out of the skull, swells into a ganglion, and is immediately joined by a portion of the tenth or accessory nerve; hence some anatomists regard the vagus as itself answering to the posterior, and the accessory to the anterior, root of a spinal nerve.

The glosso-pharyngeal nerve communicates freely with branches of the pneumo-gastric, sympathetic, facial, and accessory nerves, separates into two principal divisions, one the glossal, the other the pharyngeal; hence its name. These divisions together supply the pharynx, the arches of the palate, the tonsils, and the tongue. By its sensitive root it probably assists in communicating common sensation to all the parts just enumerated. By its motor root it excites and governs the muscular contractions of the same organs, and is the chief motor power of the pharynx in the act of deglutition. But its chief distinction is that it is a nerve of special sense. It is the gustatory nerve, or the nerve of taste. This is indicated by those experiments which render it probable that the sense of taste is seated only in those parts of the tongue and palate which are exclusively supplied by this nerve, as is shown by the experiments of Valentine. It is true that the lingual branch of the fifth nerve is also distributed to the tongue, and is claimed by some as the gustatory nerve, since paralysis or division of it is followed by the loss of taste over those parts of the tongue which it supplies. But this may be from the loss of common sensation, without which special sense could not exist. At all events, in Valentine's experiments no sense of taste could be excited in those parts of the tongue which are exclusively supplied by the lingual branch of the fifth nerve. In the present state of our knowledge, however, it must be regarded as an open question whether the glosso-pharyngeal is not exclusively the nerve of taste; or whether both this and the lingual branch of the fifth may not be gustatory nerves of the parts of the tongue which they severally supply.

THE VAGUS, OR PNEUMOGASTRIC NERVE.—There is no other nerve connected with the cerebrum which supplies so many different organs, and those on the action of which life so immediately depends, as the pneumogastric. Its principal branches are distributed to the muscles and mucous membranes of the pharynx, larynx, trachea, bronchi, lungs, heart and great arteries, and the stomach. It is a mixed nerve, the branch of the accessory being its anterior root; it communicates both sensation and motion. Its double function is proved by the ordinary evidence, that irritation of its posterior root produces pain, of its anterior root, convulsive muscular contraction.

By its motor branches it gives their chief motor power to the muscles of the pharynx, the soft palate, the glottis, the larynx, the bronchi, and the œsophagus and stomach. By its sensitive branches it communicates sensibility, especially to the mucous membrane of the pharynx, larynx, trachea, bronchi, lungs, and stomach. It is by branches derived from this source that the larynx acquires that acute sensibility by which the glottis guards the entrance of foreign bodies into the air-passages. It is above all by its supply of excitor fibres to the lungs that the mucous membrane of the lungs receives that impression, that sense of the necessity to breathe, which being transmitted by incident fibres to the medulla oblongata, excites, through reflex fibres, the action of the respiratory muscles. It is thus the great excitor nerve of respiration. It is also principally through branches of this nerve (the cardiac) that the influence of the brain is transmitted to the heart; that mental emotions disturb, that is, excite or depress, the actions of the heart; and it is by the same channels that the mind acts upon the stomach, and the stomach upon the mind.

By the conjoint influence of its motor and sensitive branches this nerve co-operates in the production and regulation of the voice in speaking, singing, and so on; one set of its fibres, the inferior laryngeal (motive), determining the contraction of the muscles that vary the tension of the vocal cords; and another set of its fibres, the superior laryngeal (sensitive), conveying to the mind a consciousness of the state of these muscles necessary for their continual guidance. In like manner, both branches co-operate in the action of ordinary breathing, in the regular slight dilatation and contraction of the glottis in the acts of expiration and inspiration, and still more evidently in those of coughing, sneezing, and other forcible respiratory movements.

Seeing, then, the number of vital organs which this nerve influences, and their absolute dependence on it during every moment of existence, we can understand the reason of the exceptional course which, it has been shown, is taken with respect to the position of this nerve; why, instead of being placed near the organs which it is to animate and govern, which would be low down in the neck or in the chest, it is carried absolutely within the cranium, and so is there rendered safe from the accidents and shocks, to which the vertebral column is so imminently and constantly exposed.

THE NINTH, LINGUAL, OR HYPOGLOSSAL NERVE.—This nerve is devoted mainly to the tongue. It influences all the muscles which contribute to the manifold movements of this organ. It is probably, in itself, purely motor, though it has a borrowed sensibility from sentient nerves. From its almost exclusive action on the muscles of the tongue it is often called the motor linguæ, and the varied and important offices of the tongue is indicated by its deriving supplies of nerves from so many different sources.

THE ACCESSORY NERVE.—According to the view stated, this nerve constitutes the motor portion of the *pneumogastric* nerve. Whether this be correct or not, it is admitted that the pneumogastric derives many of its motor fibres from the accessory nerve. Its influence is exerted principally on the powerful muscles of the shoulder and upper part of the chest, which, besides their ordinary offices, are called out into extraordinary action in energetic and violent acts of respiration. It thus becomes an important respiratory nerve when, from disease or otherwise, the ordinary movements of respiration fail duly to carry on the circulation of the blood through the lungs.

CHAPTER XXVII.

STRUCTURE OF THE BRAIN.

The brain is that part of the cerebro-spinal axis which is contained within the cavity of the skull. (Fig. 32).

The like provisions are made for its protection and nourishment as for the spinal cord. Its chief protection, like that of the cord, is derived from the solid case in which it is enclosed. The figure, position, relation and mode of connection of the eight bones that compose the cranium, and the admirable adaptation of the whole for containing and defending the brain, have been already described.

Within its solid case the brain, like the cord, is enveloped in three membranous coverings, the same in structure as those of the cord, and bearing the same names.

1. Pia Mater.—The pia mater of the brain, like that of the cord, closely envelops the nervous matter, dips down between all its convolutions, follows and covers its minutest fissures and windings, and gives an internal lining to its larger cavities.

The arteries of the pia mater, the carriers of nourishment to the brain, spread themselves out on this delicate tissue, and divide upon it into very minute branches, before they enter the tender cerebral substance, in order to temper and regulate the force of the current of the blood.

The quantity of blood transmitted to the brain is very great. It is conveyed through four channels, by four large arterial trunks, termed the two internal carotids and the two vertebrals; the two first entering the brain at the fore part of the head, through two canals made for their passage in the substance of the temporal bone; and the two last entering the brain at the back part of the head, by an imperfect osseous canal in the six upper cervical vertebræ.

So large and frequent are the communications between these systems of vessels that, if an impediment to the circulation occur in any one of them, it scarcely at all influences the flow of the general current, because the blood readily finds its way through the unobstructed communicating branches. Thus, if a ligature be placed around all the great cerebral trunks on one side of the body, there is no interruption to the circulation; but if the arteries on both sides are tied, the consequence is instant death.

Extraordinary care is taken, by numerous and special provisions, to secure the free return of the blood from the brain by the veins, which do not accompany the arteries, like the other veins of the body, but are widely dispersed, and are ultimately collected into the large tortuous canals already described under the name of sinuses.

2. The Arachnoid Membrane.—The arachnoid of the brain, like that of the cord, is everywhere in contact with the pia mater, in some parts closely, but in others, especially at the base of the brain, very loosely. It is spread uniformly over the surface of the brain, covering all its fissures and convolutions, but not penetrating between them.

Upon the roots of all the nerves that go off from the base of the brain, the arachnoid forms pouches precisely similar to those on the roots of the spinal nerves, and is thence reflected on to the dura mater, which it closely lines throughout its whole extent. The mechanism and its object are the same in both. It has been shown that as there is no division between the spinal and cranial cavities, the cerebro-spinal fluid passes freely from the one into the other. Its quantity varies much in different parts of the head, but it is most abundant around the medulla oblongata, the centre of life, because the seat of respiration. This vital organ is therefore completely surrounded by this protective fluid, precisely as the cord is suspended in it in its canal. Its action on the brain is the same as on the cord. When, from any cause which retards the free return of blood from the head, an accumulation takes place, the cerebro-spinal fluid retreats into the arachnoid space of the cord; and when an accumulation occurs both in the head and spine, relief is afforded by the recession of the fluid into the multitudinous pouches already described around the nerves both of the cranium and spine.

3. Dura Mater.—The external covering of the brain is one of the densest, thickest, and strongest membranes of the body. It completely envelops the surface of the brain with all its appendages. It adheres to the inner surface of the cranium as the periosteum does to the bones of the other parts of the body, and being itself lined by the arachnoid is internally everywhere smooth and polished. It gives off a number of dense strong processes which enter between the main divisions of the brain; as

1. The Falx, so called because it bears some resemblance in shape to the Greek sickle or scythe. It extends from before backwards, between the two hemispheres of the brain, and steadies these principal cerebral masses, and prevents them from pressing on each other.

2. The Tentorium, is continued laterally from the falx, and forms a roof or vault over the cerebellum.

3. The Falx Minor, is placed between the lobes of the cerebellum, and performs for the latter organ the same office as the falx does for the cerebrum.

The structure and disposition of these powerful membranes, the arrangement of which it is impossible to follow by a verbal description, show that they form admirable mechanical contrivances for the office assigned to them; namely, to steady, support, and protect from pressure the large, but tender masses that make up the brain.

It has been shown that the dura mater serves as a periosteum to the inner surface of the bones of the cranium. Externally the cranium is covered by a true periosteum like the other bones of the body. Both membranes are highly vascular, and there is a direct communication between the one and the other; for the vessels of the external periosteum, piercing the substance of the bones, are continuous with those of the dura mater, and so indirectly with those of the pia mater. Hence it may be said that the arteries of the external skin are in direct communication with those of the dura mater, and ultimately even with those of the pia mater—a most important relation, which explains why a blow upon the scalp so often produces disease of the brain, and why a dangerous turgescence of blood-vessels within the brain may, in certain instances, be relieved through blood-vessels on the outside of the cranium.

The brain consists of an assemblage of different masses of nervous substance, the form, position, magnitude, structure, and relation of which are definite and invariable. They have been recognised as distinct portions of the nervous system from the earliest days of anatomy. They have received names which have been handed down from remote antiquity, derived generally from their supposed resemblance to some familiar object—a resemblance commonly fanciful, and often misleading. Inexpressive and even objectionable, however, as some of these names may be, it is now difficult to alter them, and they must be retained, at least to some extent.

The principal masses that make up the brain are the medulla oblongata (Fig. 107); the cerebrum (Fig. 107, middle and anterior lobe); and the cerebellum (Fig. 107): the whole taken together is often called the encephalon, from *εν*, within, and *κεφαλη*, the head.

1. THE MEDULLA OBLONGATA.—The medulla oblongata is a direct continuation of the spinal cord, the latter taking the name of medulla oblongata immediately it emerges from the vertebral canal and passes through the foramen magnum into the skull. (Fig. 35). The Latin term *medulla* (marrow), has been given to it, from the erroneous notion that it partakes of the nature of that substance: it is called *oblongata* from its oblong figure.

Compared with the spinal cord, the medulla oblongata is of large size. It acquires its greater magnitude partly in consequence of entirely new bodies, hereafter to be described, being added to it, and partly in consequence of the deposition of a large quantity of vesicular neurine in its interior. By the addition of the new bodies its structure becomes much complicated. It is remarkable also that its neurine is disposed in quite a different manner from that in the interior of the spinal cord. In the spinal cord it is doubly concentric (Fig. 104); in the medulla oblongata it is disposed in isolated masses (Fig. 107)—circumstances which indicate that it is a new organ, connected with the spinal cord, but different from it.

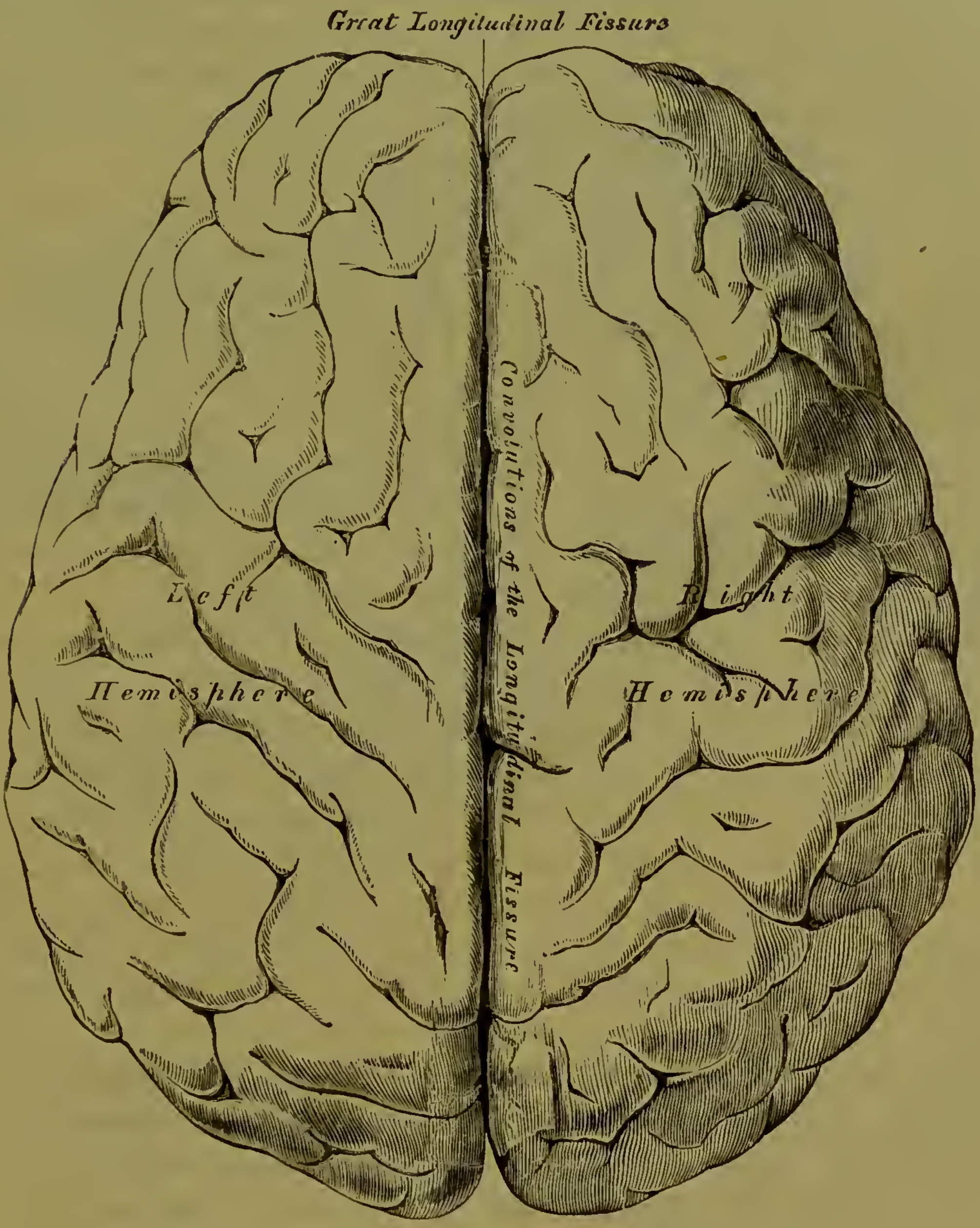
2. The Cerebrum.—The cerebrum is the large nervous mass situated at the upper part of the skull, the cavity of which it completely fills. (Fig. 31.) The name appears to have been originally written *carabrum*, from *καρη*, the head. By anatomists it is often termed the brain proper; but popularly the word brain is used to denote all the parts contained within the skull, or the whole encephalon. The English word brain is of Saxon origin, and appears to be derived from a Saxon root, which signifies to *spread out*, or *extend;* as if the brain were an extension of the spinal cord and medulla oblongata. If this be the true etymology, and if the name were given under this conception, our Saxon ancestors must have anticipated the discovery of modern anatomists; but this is scarcely probable.

The cerebrum is divided into two equal halves, termed hemispheres. Each hemisphere is of an oval shape, somewhat resembling an egg cut longitudinally into two equal portions. Its surface is disposed in folds, termed *convolutions*. (Fig. 108.) Its convolutions are separated from each other by deep fissures, so that the external surface presents the appearance of a series of folds; some being placed parallel, and all pursuing a tortuous direction (*ibid.*). These folds seem, on a superficial view, to be disposed without much order; but on careful examination, and especially with the aid of comparative anatomy, they are found to be regular in their form, position, direction, and relation. They are, indeed, of different sizes, that is, of different length and breadth in the brains of different animals, and in different parts of the brain in the same animal, as is demonstrated by comparative anatomy. Some of them are transverse, while others are longitudinal (Fig. 108); but whatever may be their diversities in other respects, they invariably pursue, in the same region, the same direction; the transverse never becoming longitudinal, nor the longitudinal transverse. Some are primary and universal; others are secondary and subordinate, as is proved by comparative anatomy.

In order to carry on the description of the brain, it is necessary to remove it from the skull. For the purpose of examination it is commonly placed on its upper surface. There is then brought into view what is called the base of the brain. (Fig. 107.)

Each hemisphere is now seen to be divided into three large masses (Fig. 107); these are called lobes (*ibid.*); they are named according to their position from before backwards, anterior, middle, and posterior (*ibid.*). There is perfect regularity in the relative form, size, and position of the cerebral lobes. Each is distinguished by distinctive and unmistakeable anatomical characters.

Fig. 108.


Great Longitudinal Fissure
Convolutions of the Longitudinal Fissure
Left Hemisphere
Right Hemisphere

Upper surface of the brain, the pia mater having been removed.

3. The Cerebellum.—The word cerebellum is the diminutive of cerebrum, or little brain. It is situated at the base of the skull (Fig. 32, *b*), in a cavity expressly excavated for it in the occipital bone. (Fig. 34, *d.*) It is placed under the posterior lobes of the cerebrum (Fig. 32, *a*), which completely cover it, and in man even pass beyond it. On viewing the human brain from above,

therefore, in its natural situation, there is no appearance of cerebellum. (Fig. 108.)

The cerebral lobes, though extending over the cerebellum, are not in contact with it, a special provision being made to protect it from the pressure of these large and heavy masses by the expansion of the process of the dura mater, termed the tentorium, already described, which forms a vaulted roof on which the cerebral lobes rest, and under which the cerebellum lies in perfect safety.

The cerebellum consists of a central body continuous across the median plane, called the vermiform process (beneath medulla oblongata, in Fig. 107), and of two large lateral masses, termed hemispheres. The vermiform process is the fundamental part of the organ, as is shown by comparative anatomy; for in tracing the cerebellum through the series of animals, it is found that the vermiform process is the typical cerebellum; this being the real cerebellum in all the animals which possess the organ. In the lower classes of animals there is nothing but the vermiform process; in the higher orders the lateral masses, or hemispheres, are superadded.

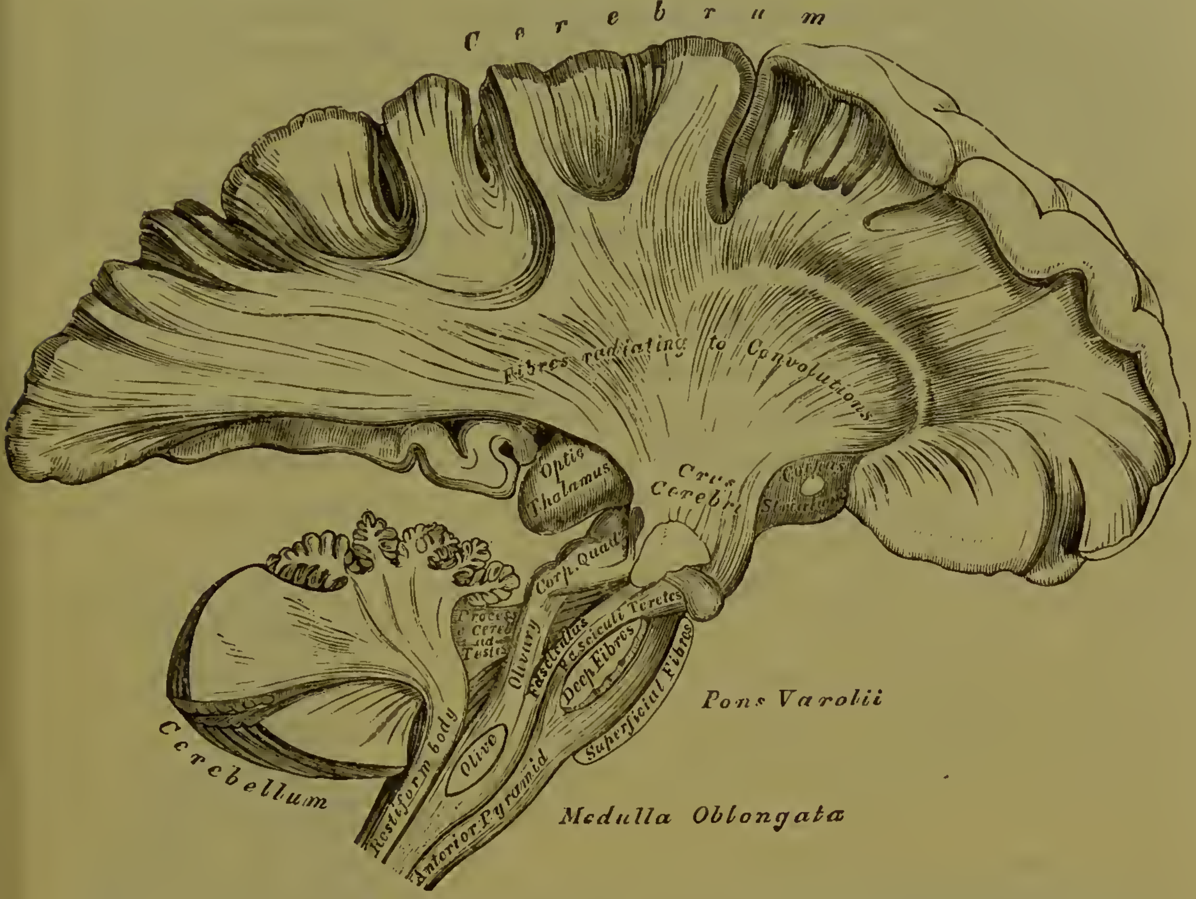
In man each hemisphere of the cerebellum is divided into lobes, which are generally described as six in number (Fig. 107); and these are again subdivided into innumerable laminæ, or plates, by fissures that vary from a line to half an inch in depth, or more. (Fig. 107.) The external surface of the cerebellum presents a striking contrast to that of the cerebrum; because its neurine is folded in a different manner, forming laminæ, or plates, not convolutions. One purpose is equally answered by both arrangements, namely, the packing of the largest amount of grey neurine, the dynamic portion, in the smallest space.

Fig. 109 exhibits the several parts of the encephalon just described in section. 1. The cerebrum, which entirely fills the upper portion of the skull. 2. The cerebellum, occupying the base of it, and overlapped by the posterior portion of the cerebrum. 3. The appearance of the convoluted surface of the cerebrum. 4. The appearance of the laminated surface of the cerebellum. 5. The relative position and magnitude of the spinal cord and medulla oblongata. This plate should be carefully studied.

If a vertical section be supposed to be made through the deep fissure that separates the cerebral hemispheres from each other (Fig. 108), it would divide them into two equal and perfectly corresponding parts. These masses are therefore double and symmetrical.

Such are the appearances presented by the brain on its external surface, and which are visible without dissection. The whole of this outer surface is of a grey colour, because it everywhere consists of grey substance, which so completely envelops the white, that it is commonly said to surround it as the bark does the inner parts of a tree; and hence it has derived the additional name of the cortical substance.

Fig. 109.



The columns of the medulla oblongata, and their connection with the cerebrum and cerebellum.

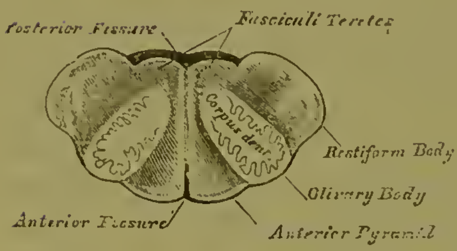
The inner parts of the brain consist of—1. A vast, and, at first view, a confused mass of white medullary matter. When in a perfectly natural state it presents to the naked eye but little appearance of a fibrous or tubular structure. It is so soft and delicate that it requires the utmost care and skill to discover and exhibit its true anatomical characters. 2. Certain masses composed of a structural combination of tubular and vesicular neurine. These masses form distinct bodies, which possess a definite figure and size, and are placed in a regular series along each side of the median plane, and extend from the medulla oblongata to the white substance of the hemispheres. 3. Extended masses of various figures and sizes, consisting chiefly of tubular neurine, having a definite and varied structure, and forming an apparatus of union, which consists of two sets of fibres, one set uniting the opposite and symmetrical halves of the brain, and the other the component parts of each hemisphere.

The structure and relations of the individual parts of the brain, especially when considered as forming a united whole, are so complex and intricate, that it seems at first view difficult, if not impossible, to describe the organ in an intelligible manner. The difficulty is increased by not having the object itself before us. Still, by considering only the fundamental parts, and by the aid of diagrams, it is practicable to convey a clear and correct conception of its organisation to any one who will give due attention to the subject. Without some knowledge of its structure it is quite impossible to understand its functions.

It will be convenient to commence the description of the more interior and fundamental parts of the brain by an account of the position and relation of the several bodies that are placed at its base, following them in their order upwards, from the spinal cord to the cerebral hemispheres and the layers of the cerebellum.

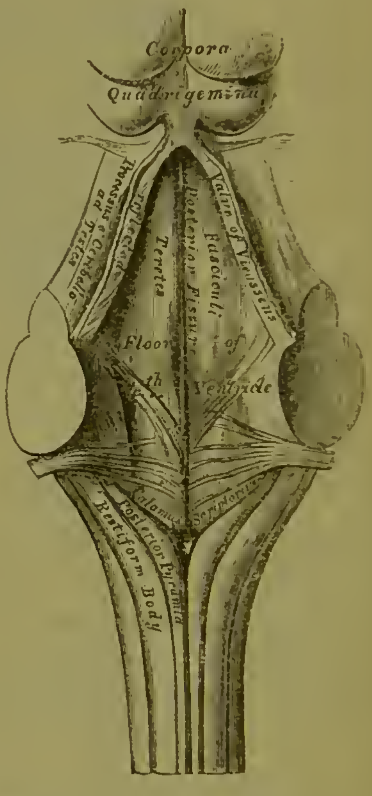
1. On the anterior surface of the medulla oblongata are visible two flattened bands or cords, which occupy its centre (Fig. 109), and which have been already described under the name of the anterior pyramids (Fig. 110, in section). As they ascend these bands gradually increase in size, and assume a pyramidal form (Fig. 109), and hence their name.

Fig. 110.



Transverse section of medulla oblongata.

Fig. 111.



Posterior surface of medulla oblongata.

2. At the sides of the pyramids, and in immediate contact with them, are two other bodies, projecting considerably, which, from their supposed resemblance to olives, are called the olivary bodies (Figs. 109 and 110, in section).

3. On the outer side of the olives are two eminences, which, from their cord-like appearance, have received the name of restiform bodies, from the Latin *restis*, a cord (Figs. 109, 110, in section).

4. Passing to the posterior surface of the medulla oblongata, behind the restiform bodies, and at the sides of the median plane, are two small elongated cords, which, from their figure and position, are termed the posterior pyramids (Fig. 111). These bodies also contain some grey matter, described by Mr. Lockhart Clarke as the "post-pyramidal ganglion."

5. Still on the posterior surface, but deeper-seated than the posterior pyramids, are a number of distinct bundles of fibres, to which attention will be again directed.

6. Returning again to the anterior surface of the medulla oblongata, immediately above the anterior pyramids and the olives, and in contact with them, is a large thick mass of neurine, about an inch in width, stretching transversely across the medulla oblongata (Figs. 107 and 109, in section). From its fancied resemblance to a bridge, expanded over the medulla oblongata, it has been called, after the name of the anatomist who first particularly described it, the bridge of Varolius (Pons Varolii).

7. At the side of the pons Varolii is placed the cerebellum (Fig. 107), a section of which displays in the interior of both its hemispheres a mass of grey neurine (Fig. 109), which, from the tooth-like edge of its very remarkable figure, is called the corpus dentatum.

8. Emerging from the upper edge of the pons Varolii are two large rounded masses, about half an inch in thickness (Figs. 107 and 109). The earlier describers of the brain thought these bodies bore some resemblance to legs, and therefore they called them, according to the fanciful nomenclature of those days, the legs of the brain—*crura* cerebri, from the Latin, *crus*, a leg.

9. Resting on the upper and inner surfaces of the crura are two large oval masses, which, from their supposed resemblance to a bed or couch, have received the name of thalami, from *θαλαμος*, a bed. They consist of an intimate union of vesicular and tubular neurine, and consequently form ganglia. Accordingly they are called cerebral ganglia, and the term posterior is added to distinguish them from two still larger ganglia which are placed on the outer side of them; namely—

10. The anterior cerebral ganglia. These latter masses are somewhat pear-shaped in figure, the basis of the pear being forwards and inwards, and the apex, or small end, lying backwards (Fig. 109). When an incision is made through them, there are brought into view numerous white striæ or streaks, and from this appearance

the masses themselves are commonly designated the *striated* bodies (corpora striata).

11. From the whole outer margin both of the thalamic (Fig. 109) and of the striated bodies proceeds a mass of radiating fibres, forming a vast fan-like expansion (Fig. 109, *fibres radiating to convolutions*), the rays extending to the convolutions of the cerebrum.

12. Next, and last, in order are the convolutions, the general figure and relations of which have been already described. They are capable of being completely unfolded and spread out into a plane surface, without much apparent injury to the nervous substance. It has been shown that they are packed into broad and deep folds, in order that the maximum of matter may be comprised in the minimum of space. When this unfolding is successfully accomplished, and they are spread out to their full extent, the enormous amount of nervous matter composing the human brain becomes strikingly apparent. This appears equally surprising on examining the extent and depth of the convolutions, as exhibited in Fig. 109, which represents the appearance presented on making a transverse section of the human brain, taken from about its centre. Packed in these folds, the skull is capable of containing a vast mass of matter without being of unwieldy size, and without the compression of its contents.

The structure of the convolutions, when carefully examined, is found to be far more complex than is apparent on a superficial view. Even by the naked eye, however, there can be distinguished three layers of neurine alternating with each other—an external grey, a middle white, and an internal grey layer, and occasionally, especially in the posterior convolutions, a second layer of white. But when a portion is brought under the microscope, it is seen to consist of six layers, three grey alternating with three white. The arrangement of the layers is such that the white are completely coated by the grey.

13. In front of the pons Varolii, and connected with the upper surface of the crura cerebri, are placed four rounded masses of grey substance, intermingled with white fibres, called corpora quadrigemina (Fig. 109, corp. quad.), from quadrigeminus, four double, or optic tubercles, from their connection with some of the functions of the eye.

14. Lying in front of and between the upper quadrigeminal bodies, and connected with the thalami by two small bands of neurine, named peduncles, or foot-stalks, is a small mass of grey matter, called the pineal gland, which has acquired celebrity by its having been selected by Descartes as the seat of the soul. It is distinguished by the peculiarity of containing a collection of hard crystalline particles, sometimes called "brain-sand."

15. There are still two other distinct bodies belonging to the cere-

brain, called, from their white appearance, corpora albicantia, from albesco, to grow white. They are small, silvery, pea-shaped bodies, situated at the base of the brain (Fig. 107, in the centre), and united to the fornix by the two anterior pillars of that organ.

16. An apparatus of union, connecting together the several parts of the nervous system, has already been referred to under the name of commissures. The commissures of the brain consist in a few instances of vesicular neurine, but by far the greater number are composed of white fibrous matter.

These structures must be regarded as constituent parts of the masses to which they belong. They make up a large portion of the encephalon. The delicacy and elaborateness of their structure, no less than the great extent of their development, indicate their importance. It is, however, quite impossible to convey an exact conception of their course without the presence of the objects themselves.

When a careful and successful dissection has traced any one of these connecting masses through its principal windings, although the minutest anatomy can display only a comparatively small number of its component fibres, the mind is lost in wonder at the countless number of the individual filaments, and the intricacy of their communications with one another. Of these masses, though it costs the most dexterous anatomist many weeks of great labour to unfold even their principal portions, the following brief notice must at present suffice.

17. On inspecting Fig. 112, there is seen lying upon the thalami a remarkable triangular body, consisting of white neurine, termed the fornix, from the Latin fornix, an arch, because it spreads over and covers a large fissure, hereafter to be described, called the third ventricle. It has a most extended and intricate course. All its fibres take a longitudinal direction, and hence it has received the name of *The Great Longitudinal Commissure.* It unites together the several parts of a single hemisphere (Fig. 112).

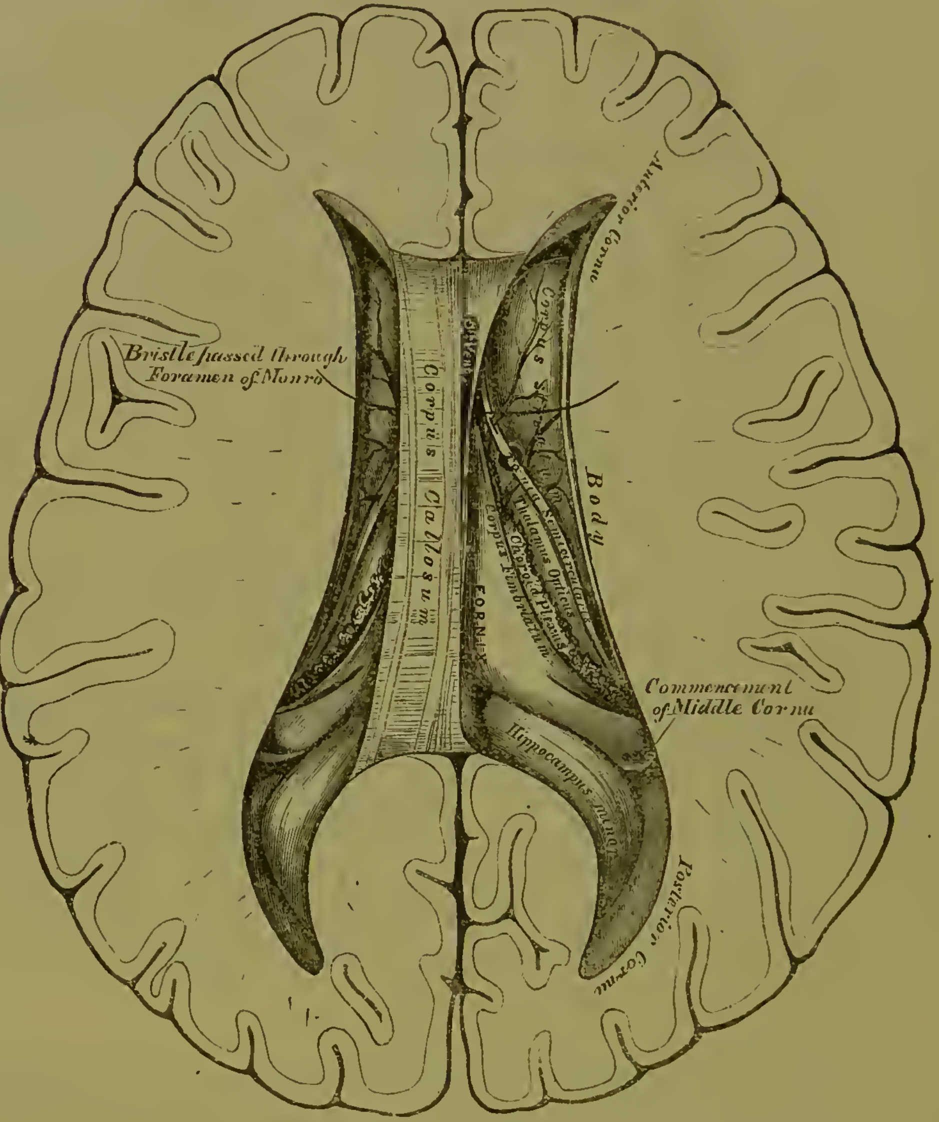
18. A similar set of longitudinal fibres placed above the body, next to be mentioned, the corpus callosum, unites together the upper convolutions; it is called the Superior Longitudinal Commissure.

19. Between the two hemispheres, and extending transversely across the median plane, lies a large mass of white fibres, to which, in consequence of being somewhat firmer than the other portions of the brain, the name of corpus callosum is given (Fig. 112). It consists of an immense mass of fibres, which take a transverse direction, and hence it is called *The Great Transverse Commissure.* It unites together the opposite cerebral hemispheres (Fig. 113, in section).

20. Emerging from both hemispheres of the cerebellum, and crossing transversely the median plane, is a large and thick mass of white

fibres, which form the arched portion of the body, so often mentioned under the name of the pons Varolii (Fig. 107). These fibres are wholly commissural; and as they take a transverse direction, and belong especially to the cerebellum, they are called the transverse commissure of the cerebellum. They unite together the opposite cerebellic hemispheres.

Fig. 112.



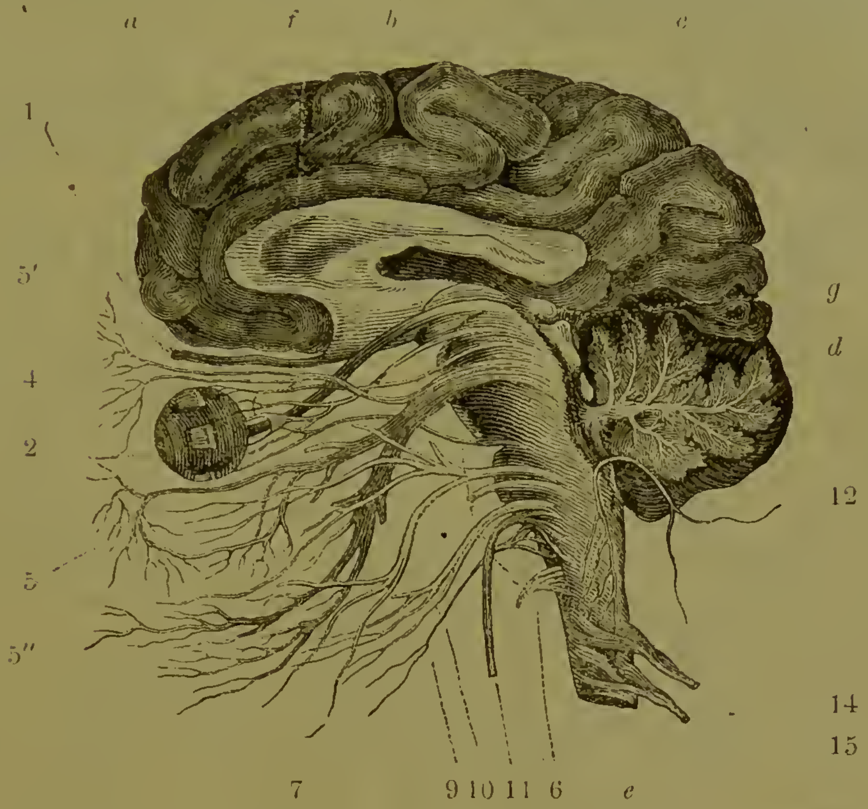
The lateral ventricles of the brain.

21. Lastly, proceeding from the middle lobe of the cerebellum, and extending to the quadrigeminal bodies, there is a thin layer of white fibres, called velum interjectum, that is, "interposed veil," and also on the sides of this two cords having a somewhat similar, but more extensive, connection with the cerebrum, called processes, from the cerebellum to the quadrigeminal bodies (processus cerebelli ad corpora quadrigemina) (Fig. 109). The whole of this structure is well denominated

"inter-cerebral commissure," as it forms the great connecting apparatus between the cerebellum and the cerebrum.

From the varied configuration and course of the several bodies which thus make up the encephalon, it is obvious that they cannot be everywhere in apposition. Between the divergence of some and the convergence of others interspaces occur, and these have received the name of ventricles, from ventriculus, the diminutive of venter, a belly. They do not form real cavities. They are simply fissures left between those figured parts of the brain which become contiguous, but not continuous. There are commonly enumerated and named four of these principal fissures; two of which, being situated at the sides of the median plane, are called the lateral ventricles, and the others, placed near the base of the brain, are termed the third and fourth ventricles. The arachnoid being reflected from one figured

Fig. 113.



Section of the brain, cerebellum, pons, and medulla oblongata. Vertical section of the cerebrum, cerebellum, pons Varolii, and medulla oblongata. *a*, anterior lobe of the brain; *b*, middle lobe; *c*, posterior lobe; *d*, cerebellum; *e*, medulla spinalis; *f*, section of the corpus callosum. The lateral ventricles of the brain are situated on either side of the corpus callosum, which assists in forming their upper wall. *g*, optic lobes: 1, olfactory nerves; 2, the eyeball, from which may be traced the optic nerve as far as the optic thalami or lobes. Close to this is the nerve of the third pair. 4, the fourth pair, distributed, like the third, to the muscles of the eyes; 5, superior maxillary branch of the fifth pair; 5′, ophthalmic branch of the same pair of nerves; 5″, inferior maxillary branch of the same pair of nerves; 6, sixth pair, proceeding to the abducentes muscle; 7, facial nerve;—under the origin of this nerve may be seen a portion of the acoustic; 9, nerve called glosso-pharyngeal; 10, pneumogastric nerve; close to it is, 12, the spinal accessory; these three nerves, the glosso-pharyngeal, pneumogastric, and spinal accessory, are by some reckoned as one pair; 11, the ninth pair of some, and the eleventh of others, called also hypoglossal; 14 and 15, cervical nerves.

surface to another, may contain fluid in the interspaces. In health there is probably merely sufficient fluid to prevent the agglutination of the surfaces, but in disease this is capable of being greatly accumulated; and when it is so, it constitutes one form of what is commonly called "Water in the Head."

There remains to be described the course of the fibres, which form distinct, continuous tracts from the spinal cord to the convolutions of the brain.

1. Course of the Anterior Pyramids.—It has been shown that a fasciculus from the anterior nerve-roots unites with the longitudinal fibres of the cord, and that both ascend together into the anterior pyramid (Fig. 109). In the pyramids, a definite anatomical disposition of the fibres takes place, which must be regarded as one of the most fundamental facts in the anatomy and physiology of the whole nervous system; consisting of a decussation of their fibres across the median plane, so that the fibres of the right anterior part of the cord pass over to the left side of the encephalon, and the left to the right, as is shown in Fig. 109.

After their decussation, the fibres pass through the pons Varolii (Fig. 109), where they join the main bulk of the fibres of the olives (Fig. 109). On issuing from the pons Varolii they advance to the crura cerebri, of which they form the under and outer portion (Fig. 109). Thence, proceeding with a radiating course to the striated bodies, they penetrate these masses, receive large accessions of fibres from them, emerge from their outer border, diverge in every direction to form the great fan-like expansion already described (Fig. 109), and thus radiating, pursue their way to the anterior and middle lobes of the cerebral hemispheres, in the grey matter of which they are lost.

2. The Olives.—The fibres of the olives, like those of the anterior pyramids, pass through the pons Varolii in a plane above that of the pyramids (Fig. 109); advance to the crura cerebri, of which they form the upper part; proceed to the thalami, into which they enter; and thence emerging, pursue the like radiating course to the posterior cerebral convolutions (Fig. 109); one portion of this tract also passes into the optic tubercles.

3. The Posterior Pyramids.—From the sides of the posterior median fissure, continuous with the posterior fasciculi of the spinal cord, in a plane deeper than the other tracts, two narrow columns, called the posterior pyramids, ascend and reach the medulla oblongata. Here they form a distinct decussation, precisely similar to that of the anterior pyramids; an anatomical fact which had been long suspected by anatomists, and positively affirmed and even described by Bell, but erroneously, as is shown by the subsequent researches of Mr. Solly.

who was the first to demonstrate the true anatomy of this structure. Fig. 111 is a drawing from Mr. Solly's dissection, which exhibits fibres of comparatively large size passing across from one side of the median plane to the other; the decussation taking place about an inch distant from that of the pyramids. An inspection of this figure further shows that some few fibres of this tract pursue their upward course on the same side of the median plane, without at all entering the decussation, a fact of some interest, as affording a clue to the true explanation of certain obscure phenomena hereafter to be noticed.

After their decussation, these fibres pass upwards, enter the crus cerebri, and pursue their course to the cerebral convolutions.

4. RESTIFORM COLUMNS.—These cord-like bodies are formed principally of fibres from the posterior part of the spinal cord, and partly of fibres from its antero-lateral columns. They pass in a curved direction, in a plane below the olives, where, from their arched form, they are called the arciform fibres. They ascend to the cerebellum, contribute to form its crura, and penetrate into the substance of its hemispheres. They thus connect the cerebellum with the medulla oblongata, and so with the spinal cord and brain, and are accordingly named "processes from the cerebellum to the medulla oblongata" (processus a cerebello ad medullam oblongatum). They convey to the cerebellum motor and sentient fibres from the spinal cord, and thus are to the cerebellum what the crura cerebri are to the cerebrum.

5. FIBRES CONNECTING THE CEREBELLUM WITH THE CEREBRUM.—In describing the commissures of the brain it was stated that a thin layer of white fibres proceeds from the middle lobe of the cerebellum, called the "interposed veil" (velum interjectum), and extends to the optic tubercles; and that at the sides of this are two cords which also extend from the cerebellum to the optic tubercles, and which are therefore called processes from the cerebellum to the optic tubercles. This apparatus unites the cerebellum and the cerebrum to each other.

And thus are established those anatomical connections between the spinal cord and the cerebral and cerebellic masses which constitute the conducting apparatus for voluntary motion and sensation.

Such is an account of the Encephalon, as far as it can be described in words and represented by drawings. With a knowledge of so much of the structure as is here given, brief as it is, what is known of the physiology may be communicated; but without it, no clear and correct conception of the subject can be conveyed.

CHAPTER XXVIII.

Functions of the medulla oblongata, and of the nervous masses situated between the medulla oblongata and the cerebral hemispheres.

As the medulla oblongata forms an integral part of the spinal cord, the force which it possesses is essentially of the same kind; but as it presides over the vital action of respiration, its functions assume a more important character. Animal existence depends immediately and directly on the act of breathing, and this act depends on the medulla oblongata, which must, therefore, be regarded as the most essential of the nervous centres, surpassing, in this respect, both the spinal cord and the brain. These latter organs may have their actions temporarily suspended—as is seen in paralysis of the legs caused by fracture or concussion of the dorsal region, and in the insensibility following the like injuries of the skull—without the necessary and immediate destruction of life; but injury to an equal extent of the medulla oblongata is inevitably followed by instant death. It is, therefore, as has been already shown, more carefully defended by the protective apparatus of bone, elastic cartilage, and cerebro-spinal fluid, than the cord or brain. To this statement, however, there is an exception with regard to the upper portion of the spinal cord, from which the nerve of the diaphragm, or great muscle of respiration, arises; and this for the reason below explained.

The medulla oblongata is likewise the seat of another vital function essential to the maintenance of life. It is the centre of the co-ordinated movements necessary in the act of deglutition, as is proved by the persistence of the power to swallow after the entire destruction of the cerebrum and cerebellum; by its existence in acephalous infants; and by its complete arrest when the medulla oblongata is injured.

The very point of the medulla oblongata, whence the power of exciting these combined movements issues, appears to be ascertained by an experiment of Müller, who found that if its external surface be carefully removed, and its interior cautiously approached to within a few lines of the spot from which the pneumogastric nerves arise (Fig. 107, 8), respiration is undisturbed; but that when this part is divided, all the movements instantly cease.

Respiration is a reflex action. The nervous apparatus which forms its special seat will clearly appear by a careful consideration of the following facts and illustrative diagram.

It has been amply proved by experiment that the ordinary act of inspiration is excited by the stimulus of carbonic acid gas momentarily accumulated in the ultimate bronchial tubes, in the intervals between each respiration, acting on the peripheral extremities of the pneumogastric nerve; and that the impression so excited passes to the medulla oblongata, on the reception of which this dynamic centre transmits its nervous force to that portion of the spinal cord where the nerve of the diaphragm arises, by which conductor this great muscle is stimulated to action, inspiration being the result. And this process may be regarded as a typical representation of the excito-motory action.

The following cases illustrate the fatal results of injury to this vital portion of the nervous system:—

A man fell from a height, and lighted on the ground upon both shoulders; the violence of the fall fractured the first vertebra of the spinal column, the atlas, and the tooth-like process of the second vertebra, the dentatus (Fig. 42). The fractured bones, no longer capable of retaining their natural position, pressed on the medulla oblongata; the instant that pressure took place the breathing ceased.

A man fell upon his head and fractured the occipital hole through which the medulla oblongata passes into the cranium (Fig. 35). He lay in the hospital for some time without exhibiting a symptom to create alarm. He chanced during this period to make no movement of the head to displace the broken pieces of bone. He had given thanks to the assembled governors of the hospital, and had returned into the ward for his bundle. He turned round to bid adieu to the other patients. By that motion the pieces of fractured bone were forced upon the medulla oblongata, and crushed it. He fell and expired in an instant.

A patient had a deep ulcer in the back part of the throat, which destroyed the transverse ligament that holds the tooth-like process in its place. The moment this support was gone, the process was thrown back, so as to compress the medulla oblongata: the head fell suddenly forward, and the patient expired without taking another breath.

From all these facts we may correctly regard the medulla oblongata as the primum mobile of life. But phenomena have been observed in relation to this organ which have led some physiologists to attribute to it a still more extensive range of function, and to regard it as the true seat of sensation and volition. And the evidence of this appears, at first view, to be irresistible. For it is proved, both by experiment and disease, that the entire cerebrum and cerebellum may be wanting, or may be removed part by part, and yet the powers of feeling and of willing seem to remain entire. When no other part of the nervous system is left but the medulla oblongata and the vertebral portion of the spinal cord, an animal seems to give precisely the same manifestation of feeling as it would do were it in a perfectly natural state.

Thus, if the skin be irritated, the limbs move, and a cry may even be uttered; but all the movements which persist after removal of the brain, when carefully observed and rightly interpreted, are found to be either simple convulsive or locomotive movements, the latter varying according to the class of the animal. In a frog, for example, by puncture of the skin of the cloaca, after decapitation, the precise motions of leaping and swimming are induced as in living legs. In a rabbit under similar conditions, all the complex motions of the toes, feet, legs, and thighs, required in progression, are excited. In these experiments, the animal may even utter cries which it is difficult to believe can be unconnected with sensation. Yet it is certain that they are so; for extended observation and research clearly show that in this case the cry, like that of the new-born infant, is in reality a mere physical phenomenon, the mechanical result of expiration.

These curious results, simulating so closely those of consciousness, naturally led physiologists to infer that, even when the brain is removed, sensibility remains. As long as motion was regarded as the indubitable and invariable sign of sensation, it was impossible to arrive at any other conclusion. But we now know that there is no such certain connection. We have in our own bodies unquestionable proof to the contrary—every time we swallow, every time we breathe, every time the heart expands to receive and contracts to force outwards a current of blood. We know that in the performance of these operations the most complicated motions of the animal frame are brought into play, and carried on with promptitude and exactness, and that of all these actions we are unconscious. We know, also, that they are carried on with equal regularity and constancy during sleep. And we see, further, that in a paralysed limb the gentlest touch throws it into convulsive motions, without the perception on the part of the individual that any such motion is excited. In this case we are certain that the loss of sensation is confined to the paralysed limb, since feeling is admitted to be perfect in all other parts of the body. If, then, in such a person motion can be excited unaccompanied by sensation, can the motions of themselves prove the existence of sensation in a state in which, but for these very motions, the conclusion would be inevitable that the loss of sensation is total?

In the state of coma it is admitted that sensation is totally abolished, yet in this state the irritation of certain nervous surfaces is capable of exciting not merely a complicated series of muscular actions, but those very actions which are regularly performed by the same parts of the body when consciousness is unimpaired.

It is proved by dissection that all parts of the external surface of the frame are provided with two orders of nervous filaments, anatomically distinct from each other, and that a similar arrangement obtains in the voluntary muscles. With such an organisation, there is no difficulty in understanding that impressions may be made on the skin which do not excite sensation, and that contractions may be determined in voluntary muscles without the agency of volition.

There are two kinds of muscular motion, one the direct result of volition; for this the integrity of the brain is essential: the other, unattended with sensation, reflex action, which is capable of being equally excited whether the brain is entire or has wholly ceased to exist.

The persistence of these motions after the destruction of the brain does not, therefore, prove the persistence of sensation, but only of reflexion; and the persistence of this power is sufficient to account for all the excited and combined phenomena observed in experiment and disease.

As long as the medulla oblongata is uninjured, and in connection with the respiratory nerves, respiration and life continue; but when all the brain above it is removed, there is no more appearance of sensation and volition in the animal subject to the experiment than there is when only the spinal cord is left. The medulla oblongata has, therefore, no claim to be considered as the seat of sensation and voluntary motion, or in any direct manner as the organ of the mind.

The bodies within the cranium, situated between the medulla oblongata and the brain proper, are the Pons Varolii, the Crura cerebri, the optic tubercles, the Corpora Albicantia, the Thalami, and the striated bodies.

Each of these masses possesses a distinct and definite organisation, and is invariably placed in the same relative position, so that it must be regarded as exercising a distinct and definite function. Many efforts have been made by vivisection to determine respectively what that function is, but hitherto with little success. The masses are so intimately connected together, and it is so difficult to isolate one from the other, that there seems but small hope of ascertaining with any degree of certainty the separate action of each. Still, observation and experiment have ascertained certain facts with reference to some of them which are not without interest, as suggesting probable conjectures with regard to their office.

1. Pons Varolii.—It has been shown that the Pons proper consists of transverse fibres expanded arch-like across the median line, proceeding from the cerebellum, and forming the greater part of the Crura Cerebri. These fibres are purely commissural, and their office is to unite the hemispheres of the cerebellum with each other.

But other fibres pass through the Pons from the pyramids, olives, and posterior pyramids, without forming part of it. In the intervals between all these fibres there is a considerable quantity of grey matter, so that besides forming a part of the apparatus of union and conduction, this body must also be an active nervous centre. What its precise action is, is unknown.

2. Crura Cerebri.—The fibres that ascend from the spinal cord, in their course to the cerebral hemispheres, after passing through the Pons Varolii, are connected together in the Crura Cerebri, and thus form the greater part of these large nervous masses. These fibres consist of two distinct planes, constituting two separate tracts of nervous force. The lower plane (Fig. 109), formed by fibres from the anterior pyramids, proceed in a direct course to the striated bodies (Fig. 109), but they are joined by a few fibres from the olives (Fig. 109), which latter seem to pass into the thalami. The course of this assemblage of fibres through the striated bodies, their progressive enlargement by a constant accession of new fibres, as they ascend towards the anterior and middle lobes of the brain, and their ultimate termination in the grey matter of the convolutions of these lobes, have been already fully described.

There is good reason to conclude that these fibres are all conductors: that they constitute, at all events, the principal channels by which the nervous centre, whatever that may be, communicates nervous force to the entire class of voluntary muscles: consequently, that it is through this tract that the mind transmits its commands to the servants of its will; hence it has received the name of the great motor tract—the tract for the conduction of volition, the exciter of voluntary motion.

The fibres of the upper plane (posterior pyramid) ascending and diverging as they advance, pursue a direct course to the thalami, and thence radiate to the convolutions of the posterior lobes of the brain.

Though the fibres now described are the principal conductors to and from the cerebrum, yet as a considerable quantity of grey matter is mixed with them, and even some pigmentary matter, constituting the *locus niger*, the crura themselves must be regarded as forming also nervous centres, but their special functions are imperfectly known. It is, however, ascertained that the *locus niger* having the attachment of the third, or occulo-motor nerve (Fig. 107, 3), is the dynamic centre of the excited action by which the pupil is contracted. Thus, it has been shown by experiment that if the hemispheres of the brain be removed in a living animal, and the optic nerve be divided, leaving entire its connections with the optic tubercles, the crura cerebri, and the third nerve, on pinching or otherwise irritating the divided optic nerve, contraction of the iris follows, though, as is evident, all sensation has been annihilated.

3. Optic Tubercles (Corpora Quadrigemina).—These, as just stated, are specially connected with the excited action of the iris. If they are removed from the body, the pupil no longer contracts; but

as long as they remain entire, the power of the iris to contract continues, though the cerebral lobes be destroyed. The removal of one of these bodies produces loss of sight in the opposite eye, proving that the fibres have decussated: the removal of both bodies causes total blindness, not because they have any direct influence on vision, but because they are conductors of impressions to the seat of perception, and by their removal communication with the brain is cut off. Irritation or injury of these bodies produces convulsions, proving that they form a part of the spinal cord, and that convulsions are produced in them in the same manner as when the cord is irritated.

4. Corpora Albicantia. — Probably belong to the apparatus of union. They are formed by the Fornix, the great longitudinal commissure of the brain, and their fibres ascend to the Thalami.

5. Thalami.—It seems, on the whole, that the balance of the evidence derived from development, comparative anatomy, and experiment, is in favour of the view that the striated bodies and thalami are cerebral parts. Thus, the true cerebrum, with the striated bodies and thalami, are developed out of the primordial cephalic vesicle. Comparative anatomy shows that the great transverse fissure passing between the thalami and the optic tubercles marks the division between the true cerebral and the true spinal parts. Flourens found that up to the optic tubercles, inclusive, mechanical irritation caused convulsions, whilst none followed irritation of the thalami, striated bodies, and cerebral hemispheres. He regards the optic tubercles, therefore, as definitely limiting, on the one hand the cerebral, and on the other the spinal system.

The special action of the thalami has been very imperfectly determined. Some regard them as the actual seat of sensation, the precise part of the nervous system in which sentient impressions are perceived. But both their position and structure indicate that they are subordinate to sensation, not the seat of it; that they are conductors carrying on sentient impressions to the cerebral hemispheres. As they contain in their interior a large quantity of grey matter, they must conduce in some way to the energy and perfection of nervous action.

6. Striated Bodies.—The great motor tracts ascending from the crura cerebri in their course to the brain proceed, as has been shown, through these bodies, and receive from them large accessions of fibres. They, therefore, constitute an essential part of the medium of conduction of motor power, and they probably increase its energy. Other functions have also been attributed to both the thalami and striated bodies. Among other conjectures, it is thought by some that these grey masses generate or give origin to new fibres, which are added to those of the crura, and which proceed with the latter to the cerebral convolutions. This was the original view of Gall and Spurzheim, and it is not an improbable one.

CHAPTER XXIX.

FUNCTIONS OF THE CEREBELLUM.

Peculiar functions imperfectly known connected in some way both with sensation and muscular motion – Co-ordination of movements—Muscular sensibility—Reproduction.

The individual action of the cerebellum, apart from that of the spinal cord and cerebrum, has not yet been satisfactorily determined. It has been sought with great zeal and assiduity by some of the most eminent anatomists and physiologists, but hitherto without any very certain result. The similarity of its structure to that of the cerebrum, at least in the main points, and its intimate connection with the latter, by the inter-cerebral commissure, would appear to indicate that it performs analogous functions. Accordingly several facts, derived both from experiment and disease, favour the conclusion that it is connected in some way with sensation, which often becomes much disordered on any serious lesion of this organ. Yet it certainly is not sensible itself, any more than the cerebrum. It may be wounded deeply, it may even be sliced away in successive layers, without causing the slightest indication of pain. Nor does it appear to have any relation to the special senses, the intellectual faculties, or the psychical operations. It is clearly proved that sight, hearing, volition, memory, remain after its entire removal from the body.

There is decisive evidence that it is intimately connected with muscular motion. It would appear that the force of muscular contraction is diminished in the direct proportion of its lesion. However extensive its disease or mutilation, no stupor is induced; there is no diminution of the sensibility of any part of the body, but the muscular movements are either impaired, disordered, or entirely lost. These movements are not merely rendered feeble, but the harmony of their action is destroyed. Violent, irregular contractions are excited, while the power of springing, flying, walking, standing, and preserving an equilibrium—in other words, the faculty of combining the action of muscles in groups, is lost. Thus an animal laid upon its back cannot bring into operation the combination of muscles necessary to enable it to recover its former position. A bird flutters its wings, but cannot fly. Efforts to retain an equilibrium are like those of a drunken man. In some cases an animal in endeavouring to advance appears to be compelled by an inward, uncontrollable force, to retrograde or fly backwards. In other instances, it is brought under the influence of an internal, impelling force, causing it to roll over from side to side incessantly. Magendie states that he counted sixty of such revolutions in a minute, and has seen the revolutions continued for a week without intermission. These movements are not exactly convulsive, but seem as if they were produced by vertigo. The same results are observed in all classes of animals.

From the whole it may be inferred that the cerebellum is connected rather with motor than sentient phenomena; but to what exact extent, or of what nature, is at present undetermined. Still, however, many physiologists conceive that the cerebellum has the faculty of combining muscular movements for the purposes of locomotion, the faculty, that is, of co-ordinating these movements.

"If this view be correct," says Müller, "the cerebellum must contain a certain mechanism adapted to the excitement of the combined action of muscles, so that disturbance of its structure destroys the harmony between this central organ of combined actions and the corresponding groups of muscles with their nerves."

Opposed to this view, however, are the facts detailed as to the power of the spinal cord in the co-ordination of motion. We have seen that the action of the toes, feet, and legs, are all properly combined, as in regular progression, when no influence can be communicated to them but that derived from the spinal cord; as when the spinal cord is divided, and when, therefore, all communication below the section, between these muscles and the cerebellum, must be cut off.

It has been suggested that the cerebellum is the organ for the perception of muscular sensibility; that is, of the sensations derived from muscles, through which the mind acquires a knowledge of their actual state and position, which is essential to the action of the will upon them. The very close connection between the cerebellum and the spinal cord favours this hypothesis, which is perhaps, upon the whole, the most probable that can at present be formed.

Phrenologists regard the cerebellum as the organ of the sexual impulse. Certainly some facts have been observed in disease which appear, at first view, to favour this opinion, but they do not really prove much. Müller justly observes that the coincidence of disease of the spinal cord with the affection of the reproductive organs is much more frequent. On the other hand, the development of the cerebellum in the animal scale presents no relation whatever with the energy of the sexual impulse; while in the human being the most formidable and extensive disease of the cerebellum, nearly amounting in some cases to its entire destruction, appears to have increased rather than diminished feelings of this class.

CHAPTER XXX.

FUNCTIONS OF THE BRAIN PROPER.

By the brain proper is here meant the cerebral hemispheres and their convolutions, together with the commissural apparatus. For the reasons now to be assigned it is held as proved that these parts constitute the true and exclusive organ of consciousness. Some few writers, however, still adhere to the opinion that other parts of the nervous centres within the skull, as the thalami, the corpora striata, and even the medulla oblongata, are in some way or other immediately connected with sensation and volition; but the weight of authority, as well as of evidence, is against this view; and there is indeed a singular agreement on this subject on the part of the anatomists and physiologists who, by their dissections and experiments, have most contributed to the advancement of science; amongst whom may be mentioned Bell, Flourens, Müller, Marshall Hall, Grainger, Valentine, and so on.

The evidence that the sentient and intellectual faculties have their sole seat in the brain proper, as here defined, may be thus stated:—

1. It is admitted that the seat of these faculties is somewhere in the nervous system. No one now supposes that they reside in the viscera. Formerly, indeed, it was believed that the emotions and passions especially have their seat in the thoracic and abdominal viscera, and the prevalence of this opinion is shown by language still in common use, which ascribes to the heart joy, sorrow, and love; to the liver anger, rage, and jealousy; to the spleen irritability, sourness of temper, malevolence, and so on. But there is no other connection between these organs and the passions in question than that which arises from the general consent and sympathy that subsists between the nervous and the nutritive systems—between the apparatus of the animal and that of the organic life. There is no case on record which shows an unequivocal relation between disease in any one of the viscera, and the prevalence of any particular passion of the soul; while the evidence that no real connection of this kind exists is decisive. Instances, for example, are of daily occurrence in which disease of the heart progressively, unconsciously advances, until the rupture of its great vessels, or even of its very substance, instantaneously extinguishes life, the mind retaining all its faculties in their full vigour up to the last moment of existence. The liver, the spleen, are often found in a state of complete disorganisation, without having produced any more effect

on the mental faculties than that which naturally accompanies a disordered state of the general health. On the other hand, the connection between disease of the brain and disorder of the mind is so close and intimate that no one can doubt it. Pressure upon the brain instantly annihilates all its faculties; inflammation of it produces delirium, often amounting to frenzy; softening of it causes imbecility, idiotcy, and so on.

That the true seat of the sentient and intellectual faculties is somewhere in the brain is further demonstrated by the facts brought to light both by experiment and disease. In every case in which the connection between the brain proper and the organs of the body is interrupted, whether by direct section of the nerve-fibres, as in experiment, or by their laceration in disease, the result is constant and invariable, sensation and volition are instantly abolished in the parts thus injured. On the other hand, the moment that connection is re-established both faculties are restored. This is occasionally seen in the effects of disease, the results of which are much more to be relied on than those of experiment. Thus, when the rupture of a blood-vessel takes place in the brain, and the nerve-fibres are consequently lacerated and torn asunder by an effusion of blood, as in apoplexy, either deep coma, including the total loss of sensation and volition, is produced, or those faculties are lost on one side of the body only, or in one half of it, according to the seat and severity of the malady; but when a reparative process takes place in the part thus injured, the progress to health is marked by a gradual return of sensation and volition; so, on dividing the trunk of a nerve either in experiment or for the cure of the painful disease called fascial neuralgia, sensation of the parts supplied by the nerve is at first lost; but when in the process of time the divided nerve reunites, a result which not unfrequently happens, sensation is re-established.

2. That the seat of the sentient and intellectual faculties is in the cerebral convolutions, is further shown by the origin, course, and termination of the nerve-fibres connected with the brain. The sentient and motor traits, as we have seen, take their origin from, and terminate in, the cerebral convolutions, apparently as their source and centre. The peripheral nerve-fibres (sentient), arising from all parts of the body, ascend to the brain, and ultimately terminate in the cerebral convolutions, in the grey matter of which they are lost. On the other hand, the centrifugal nerve-fibres (volitional) spring directly from the grey matter of the convolutions, and go out to the muscles of voluntary motion, in which they terminate. Here there is a distinct, a terminal apparatus, for the double purpose of receiving impressions and of transmitting motor force to a definite class of muscles—the muscles of voluntary motion. The structure suggests the function;

suggests that it is in the cerebral convolutions that impressions are converted into sensations, and the motor force generated by which the muscles of volition are excited to action.

3. The vast and elaborately-constructed apparatus of union by which not only the several convolutions of each hemisphere, but of the hemispheres themselves, are brought into intimate communication, indicates that this is the great centre of the higher faculties of the nervous system. There is manifestly made the most careful provision to put every part, nay, almost every particle, of this extended apparatus in the closest union, as if to place the varied faculties here exercised in relation and harmony. To no other portion of the nervous system are so many other parts subordinate and subservient; in no other is the union between different parts so complex and complete.

Nor is there any other part so elaborately constructed, and so abundantly supplied with arterial blood—the two conditions of structure which indicate the highest endowment of function. No less than six plates of fibrous and vesicular nerve-substance, disposed, as we have seen, in alternate layers, are here brought into actual contact, the vesicular completely incrusting the fibrous matter: in the intervals between these layers are distributed greater numbers of blood-vessels proportionally than in any other part of the body, except in some few instances, as the lungs, where the reason is obvious in the use of this organ—the purification of the blood itself: through these channels innumerable torrents of blood unceasingly flow, and the course of these vital currents cannot be suspended even for a few seconds without the total loss of all the cerebral faculties, an organisation which cannot fail to suggest the conclusion that here, in this exact spot, encircled by the vital fluid, where the two essential parts of the cerebral system, the originators of the cerebral force, and the conductors of it meet, is the seat of cerebral power.

4. This view is confirmed by the comparative anatomy of the brain. It is admitted that the increase of intelligence is proportionate to the development of its instrument, the brain, in the entire animal series; but the progressive development of the brain consists of successive additions to the cerebral lobes and their convolutions. In the lowest class of vertebrate animals, in fishes, the cerebral lobes are composed of two small masses of nervous substance. In reptiles these masses are very much augmented in bulk. In birds they are still more enlarged. In all these classes the lobes are undivided, each hemisphere consisting only of one single mass, the surface of which is perfectly smooth and unfurrowed, without any appearance of convolutions. In the lower class of mammalia, as in the monotremata, the marsupialia, and rodentia, of which the ornithorhynchus, the kangaroo,

and the rabbit, may be selected as the respective representations, a remarkable advance takes place. Each hemisphere is divided into two; in fact two new lobes are superadded; and now, for the first time, convolutions begin to be formed. At first only a single convolution appears, which runs longitudinally along the surface of the hemisphere. Still higher in the scale the lobes not only increase in size, but the convolutions are multiplied. In the fox there are six convolutions, which, like the single one that first appears, run longitudinally from before backwards. This longitudinal direction of the convolutions is common to all the brains in which these folds first make their appearance. So also is the more important character that they are at first quite superficial, and do not penetrate deeply into the substance of the lobes. In the higher mammalia, as in the quadrumana, a third lobe is added, so that the brain now consists of three distinct lobes, an anterior, middle, and posterior; and transverse convolutions are added to the longitudinal. This new lobe, however, is as yet very imperfectly developed; it may almost be said to be rudimentary; and all the convolutions are superficial, penetrating only very little into the substance of the lobes.

In the highest class, in man, an advance takes place in the development of the brain, carrying it far beyond that of any other animal. This advancement is marked by a prodigious increase in the size of all the cerebral lobes, but particularly of the posterior, which now extend so far backwards as completely to cover the cerebellum, thus distinguishing the brain of man from that of every other animal—a distinction which is rendered still more striking by the number and depth of the convolutions, as shown in Figs. 109 and 113, which represent the appearance of a convolution in the human brain on making a perpendicular section of it. It has been elsewhere stated that the great object of the convolutions is, by an enfolding of neurine, to pack the greatest quantity of cerebral matter in the smallest space; and this drawing shows how completely this purpose is accomplished.

From the whole of what has been stated, it is clear that the progressive building up of the brain through the animal series consists of a constantly-increasing development of the cerebral lobes and their convolutions, and the vast additions made to these masses in the human brain manifestly points to the seat of human intelligence.

Comparative anatomy further shows a remarkable contrast in the different classes of animals, between the size of the central nervous masses and that of the nerves to which they give origin, significantly pointing to the true seat of the higher faculties. The bulk of the brain, as compared with that of the nerves that spring from it, is inversely proportional to the intellectual powers of the animal; so that of all creatures man has the largest brain in proportion to his slender nerves; while, on the contrary, animals with limited intellectual powers possess bulky nerves with a very small brain. This is most remarkably the case in the lower classes of animals, as in the amphibia, but it is also seen in the higher. The maximum weight of the horse's brain is 1 lb. 7 oz.; the minimum weight of an adult human brain is 2 lbs. 5½ oz.: nevertheless, the nerves at the base of the brain are ten times thicker in the horse than in the human being.

It is also very remarkable that neither the medulla oblongata, nor any of its prolongations within the cavity of the cranium, take part in the augmentations which have been traced. They do not increase with the increase of the cerebral lobes; they are not relatively larger in man than in any other animal; and some of them, as the corpora quadrigemina, are actually smaller in the human being in proportion to the size of the body than in other animals. It cannot be reasonably supposed, therefore, that the seat of intelligence is in any of these minor and subordinate masses: it is surely more probable that it is placed in the organ which these bodies contribute to form and to complete.

5. Additional evidence of the correctness of this view is afforded by the successive stages through which the human brain passes in the progress of its formation. The investigations of comparative anatomy, and the laborious inquiries that have been made into the processes of development, have led to the establishment of the surprising fact, that the human brain, from its first appearance as a semi-fluid and shapeless mass, passes in succession through the several structures that constitute the permanent and perfect brains of fishes, reptiles, birds, and mammalia. At an early period of its formation the brain of the human embryo is temporarily precisely what the brain of fishes is permanently; in another stage it becomes that of the reptile; then that of the bird, and ultimately that of mammalia. So definite and regular is the transition of the human brain through these successive phases, that an anatomist, by examining the brain of one of the lower classes of mammalia, or other vertebral animal, can determine precisely to what exact period of the fœtal human cerebrum it corresponds. But ultimately the human cerebrum passes beyond all these structures, and acquires an enormous development, not, as has been shown, of every part of it, but of the cerebral lobes and convolutions. In the first month of fœtal life, the rudiment of the anterior lobe appears: quite towards the end of the third month the middle lobe makes its appearance. At this period the optic thalami, and after them the corpora quadrugemina, appear. It is not until the fifth month that the posterior lobe is added; but from this period this lobe, together with the anterior and middle lobes, rapidly advance to completion. These anatomical facts clearly point to the conclusion that

the consummation of the organ is the completion of the cerebral lobes; and that the elaboration of the highest structure is for the exercise of the highest faculties.

6. The conclusions thus arrived at from a consideration of the structure, development, and comparative anatomy of the brain, and of its natural action in health and disease, receive a remarkable confirmation from the results of direct experiment. Among the many endeavours which have been made to determine by *direct* experiment the use of the several parts of the brain, there is a decisive one performed by M. Flourens, one of the acutest and most trustworthy observers and experimentalists of modern times. M. Flourens removed from a healthy pigeon the two cerebral lobes: these, it will be remembered, constitute in the bird the brain proper. It is known that reptiles, birds, and some of the lower mammals, survive for months after the removal of the entire brain. Accordingly this bird, deprived of its brain, survived ten months in a state of perfect health, and would in all probability have lived longer if M. Flourens had not been obliged to leave Paris.

During the whole of this time M. Flourens closely watched all the actions and habits of the animal, and the following is the result of his observations:—

He had scarcely removed the brain before the sight of both eyes was suddenly lost; the hearing and sense of smell were also gone, and the animal did not give the slightest sign of volition, but kept himself perfectly upright upon his legs, and walked when he was irritated, or when he was pushed. When thrown into the air, he flew, and swallowed water when it was poured into his beak.

He never moved unless he was irritated. When placed upon his feet, he remained upon them; when seated on his belly, in the manner that chickens do when they sleep, he appeared plunged in a sort of drowsiness, which neither sound nor light in the slightest degree disturbed: nothing but direct irritation, such as pinching, or pricking, or striking, had any effect in rousing him.

When the animal did move about, he seemed to do so without any motive or object, though there were no convulsions, nor any want of harmony in its movements. If it met with any obstruction, it did not know how to avoid it.

The pigeon was quite healthy, and five months after the operation the wound had quite healed, and a new layer of bony matter was forming.

Still it had no sense of smell or taste; neither had it any sensation of hunger or thirst; for, after allowing it to fast for three whole days, and then placing food immediately under its nostrils, and afterwards putting it into his beak, and also putting its beak into water, it did not show the slightest disposition either to eat or drink, and would have died for want of nourishment if it had not been fed by force. It seemed entirely to have lost its memory; for if it struck itself against any body, it would not avoid it, but repeat the blow immediately.

We learn from this experiment that the removal of the brain caused an immediate loss of all the functions which it has been the object of the preceding argument to show have their seat in the cerebral lobes. Sensation and volition were instantly abolished; there was no longer any memory. The special senses were also lost—vision, hearing, smell, and taste. At the same time the sensations of hunger and thirst were destroyed; the animal was plunged into a state of profound stupor; that is to say, all the true cerebral functions were annihilated. But the functions which it has been shown are proper to the medulla oblongata and spinal cord, in contradistinction to those which specially belong to the brain, remained—namely, the reflex functions. Thus, the bird moved, although without motive or object; it flew when tossed into the air; it swallowed water when poured into its beak; and it carried on respiration as regularly as in health. All these latter functions it performed; because, though deprived of its brain, the medulla oblongata and the spinal cord were uninjured, these being the parts of the nervous system in which, as has been shown, these faculties specially reside. It is impossible to devise any more striking and decisive proof of the separate functions performed by these two great divisions of the nervous system and of their true seat. But these remarkable phenomena could not be rightly interpreted at the time, now nearly forty years since Flourens experimented. It consequently happened that at the time many physiologists contended that this very experiment proved that the medulla oblongata was the seat of sensation, consciousness, and volition, because, after the brain had been removed, the animal moved when touched, and flew when thrown into the air. But it has been fully shown that the occurrence of such movements after the loss of the brain is no proof of the continuance of sensation, or of any other cerebral faculty; and that what is really demonstrated by these motions is, that there still remained unimpaired the functions proper to the medulla oblongata and the spinal cord, namely, those of reflex action.

It is unnecessary to pursue this subject farther. When all the circumstances which have been stated are duly weighed, little doubt can remain on the mind as to the true seat of the sentient and intellectual faculties.

The conditions which are essential to sensation are—

1. That an impression be made by some external object on a sentient nerve.

2. That this impression be conveyed in a continuous, uninterrupted course to the brain.

3. That the brain be in a state of integrity to receive the impression, and to convert it into sensation.

Without the external object to originate the impression there is no sensation.

Without an uninterrupted transmission of the impression to the brain, there is no sensation; for if a ligature be placed around a nerve, in any part of its course to the brain, there is no longer any feeling below the ligature. The skin may be sound, and the nerve distributed to it may be perfect, yet no amount of irritation will produce the slightest sensation.

Without the integrity of the brain there is no sensation, or only perverted sensation. Pressure upon the brain, so as to produce coma, wholly annihilates the power of sensation. In disease of the brain, as the inflammation or softening of it, there is no true perception, but pain, delirium, and feeble, incongruous, or incoherent trains of ideas.

All sensitive impressions are centripetal, from the periphery to the centre. When a sentient nerve is divided, and irritation is applied to the end still in connection with the brain, sensation is produced. When applied to the end cut off from its connection with the brain, no sensation can be excited. A sentient fibre can transmit impressions only in a direction towards the brain. A sentient fibre terminates by one extremity either at a point of the external surface of the body, as the skin, or at a point of the internal surface, as in certain mucous membranes; or in an apparatus of special sense, as that of touch, vision, hearing, and so on: by the other extremity it terminates in the brain. In most cases, as has been shown, every nerve-fibre thus terminates by a single point at its peripheral extremity, and by a corresponding point in the brain; an arrangement by which it is easy to conceive that a distinct impression may be conveyed from the extremity to the centre. There are, however, some exceptions, as in the nerve of the vestibule of the ear, which ends in loops.

It is necessary here to call to mind what has been fully stated, that there must be an absolute continuity and isolation in every individual nerve-fibre engaged in the operation. It must exercise its own endowment throughout its entire course, without communicating with the other filaments bound up with it in the same trunk. Were there a true anastomosis of nerve-fibres, as there is of blood-vessels, distinct, discriminative sensation would be impossible.

No nerve-fibre can convey more than one kind of impression. A sentient nerve can transmit only sentient impressions; a motor nerve only such as excite motion; and a nerve of special sense only such as produce special sensation; the optic nerve, light; the auditory nerve, sound. You cannot see with the ear nor hear with the eye. Every nerve-fibre is devoted to its own office, which cannot be transferred, and which admits of no substitution.

Sensation is not in the peripheral surfaces or external organs, to which it is commonly referred, but in the brain. It is difficult to believe that when we grasp a body we do not feel it with our hands, though the points of the fingers are the special seat of touch; that the sensation of sight is not in the eye, nor of hearing in the ear, nor of taste in the tongue; but that the perception is in the brain, and the brain only. Yet that this is true is proved indubitably.

1. By the fact already stated, that a ligature placed around a sentient nerve, so as to cut off its communication with the brain, instantly destroys sensation; while on the removal of the ligature, and the re-establishment of such communication, sensation is restored.

2. By the phenomena observed after the amputation of a limb. When a leg, for example, has been cut off from the body, above the knee-joint, sensation does not always cease, because the nerves have been merely divided; they still remain in the stump, and continue to exercise their accustomed functions. When impressions are excited in these nerves, the sensations are always referred to the lost part. Long after the stump is healed, frequently through life, sensations are referred to single toes, to the sole of the foot, to the back of the foot, to the skin covering it, and so on. The nerves of the stump, which came from those parts, are still in free communication with the brain, and when irritated by pressure, &c., convey to it the accustomed impressions, and, therefore, produce the corresponding sensations; a demonstration that sensation is not in the part in which the nerves once had their peripheral terminations, for they are removed from the body, but that its true seat is in the brain.

So, when a nose has been lost and a new one is formed, as is done in the Talicotian operation, by turning down a portion of skin from the forehead, moulding it into shape, and uniting it with what remains of the old nose, the new nose, as long as it retains its original connection with the forehead, has the same sensations as if it were still on the forehead; that is, when it is touched the feeling is in the forehead, but when, by dividing the flap of skin, the communication with the forehead is cut off, the sensations are no longer referred to the forehead. At first, the division destroys all sensibility in the part, but by degrees this is restored, and now, having lost its old associations and acquired new ones, from the new union it has formed, it refers its sensations in accordance with its new position, the mind acquiring the habit of referring its sensations to the parts at which it receives its impressions.

Though the brain is the sole seat of sensation and volition, yet it is itself wholly insensible, and incapable, by mechanical irritation, of exciting motion. No amount of laceration, or of any other mode of injury, induces in it the least indication of feeling, or produces the slightest muscular contraction. "Who could have believed," says Magendie, "that the hemispheres may be pricked, torn, cut, and even burnt by the actual cautery in the living animal without producing the slightest feeling; yet all observation and experience concur in proving that this is unquestionably the fact."

Motor fibres obey the same laws as the sentient. The influence of volition is propagated along motor nerves in a manner analogous to that of the transmission of impressions along a sentient nerve, but the process takes place in an inverse direction. It is always centrifugal, in the direction of the nerve going from the brain to the muscle, and never in a retrograde course. If a stimulus be applied to the trunk of a motor nerve, it excites contractions only in those muscles which are supplied by the branches of that nerve. Nay, if a stimulus be applied to a part of the fibres of a trunk, it does not affect the whole trunk, but only those fibres which immediately receive the stimulus; and consequently those muscles only are excited to contraction which are in direct communication with these particular fibres. So that every primary fibre of a motor nerve is as distinct and isolated in its entire course as the fibres of a sentient nerve, and volition sends out its commands to the muscles, or groups of muscles, under its control, by channels as definite and as insulated as those which convey sentient impressions to the brain.

On a dissection of the human brain there is brought into view an extended surface of the cerebral convolutions where the two forms of cerebral substance, the tubular and vesicular neurine, meet. This probably constitutes the Common Sensorium, where all impressions are received and consummated by being converted into sensations; where all volition arises, and whence it proceeds to the muscles of voluntary motion; and where all the intellectual faculties meet, combine, compare, co-operate.

APPENDIX.

I.

The following is a list of the Chemical Elements at present recognised, arranged alphabetically.

Aluminum.
Antimony (Stibium).
Arsenic.
Barium.
Bismuth.
Boron.
Bromine.
Cadmium.
Caesium.
Calcium.
Carbon.
Cerium.
Chlorine.
Chromium.
Cobalt.
Columbium.
Copper (Cuprum)
Didymium.
Erbium.
Fluorine.
Glucinum.
Gold (Aurum).
Hydrogen.
Indium.
Iodine.
Iridium.
Iron (Ferrum).
Lanthanium.
Lead (Plumbum).
Lithium.
Magnesium.
Manganese.
Mercury (Hydrargyrum).
Molybdenum.
Nickel.
Nitrogen.
Osmium.
Oxygen.
Palladium.
Phosphorus.
Platinum.
Potassium (Kalium).
Rhodium.
Rubidium.
Ruthenium.
Selenium.
Silicon.
Silver (Argentum).
Sodium (Natrium).
Strontium.
Sulphur.
Tantalum.
Tellurium.
Terbium.
Thallium.
Thorium.
Tin (Stannum).
Titanium.
Tungsten (Wolfram).
Uranium.
Vanadium.
Yttrium.
Zinc.
Zirconium.

II.

For many of the illustrations used in this volume, the Editor is indebted to the kindness of other writers on anatomy, &c., from whose works they have been borrowed; and takes this opportunity of thanking the proprietors of Gray's *Anatomy*, Milne Edwards' *Zoology*, and Kölliker's *Microscopical Anatomy*.

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